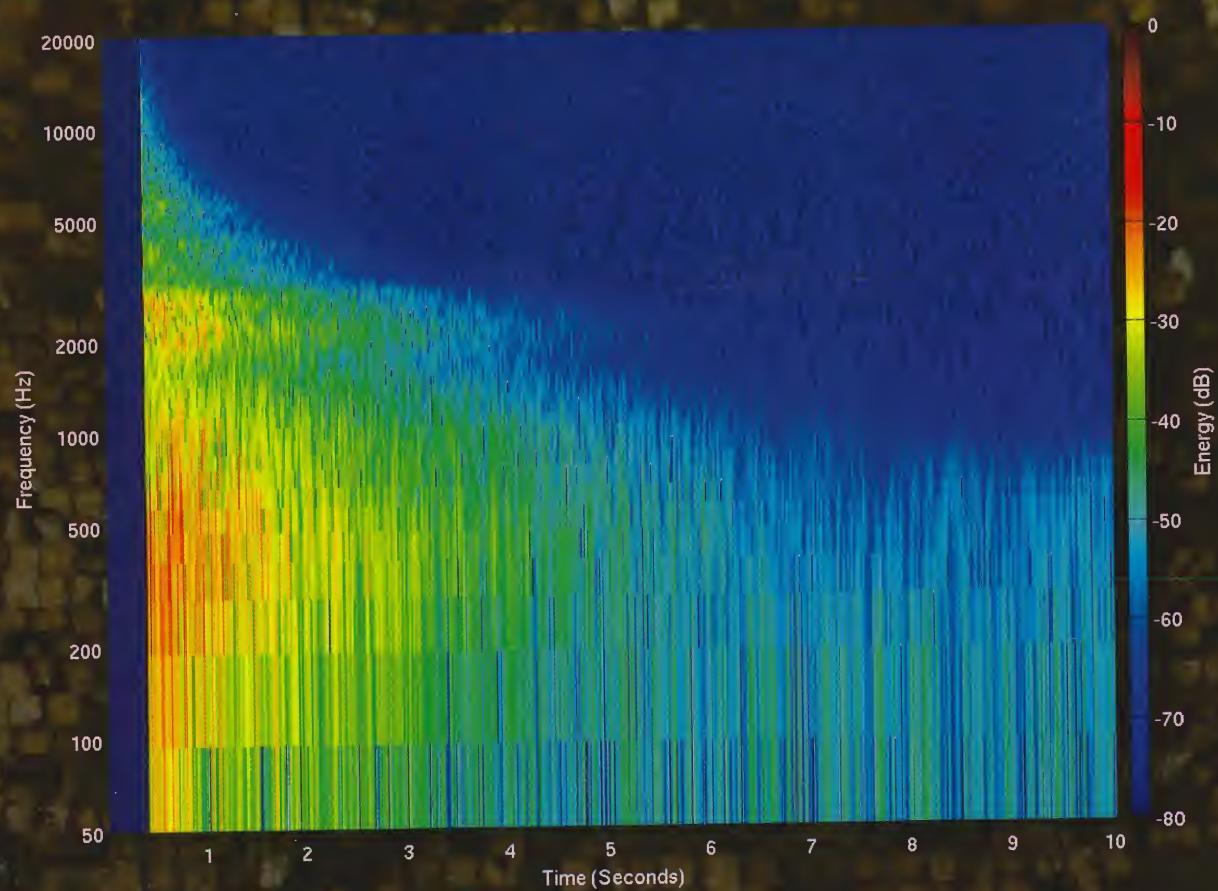


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Hagia Sophia and Multisensory Aesthetics*

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Abstract

Focusing on the sixth-century interior of the church of Hagia Sophia in Constantinople, this article explores the way marble and gold appear and their psychological effect on the spectator as recorded in Byzantine ekphrasis and liturgical texts. In turn, this optical shimmer, in Greek, marmarygma, is linked to the acoustic properties of marble, especially its capacity to reflect sound waves. The meaning of the optical and acoustic reflection is related to the Eucharistic rite and, more specifically, to the concept of animation, empsychosis. The exploration of acoustics is further deepened by the use of the sound of exploding balloons and modern digital technology to measure the reverberation time of the interior and to generate with its aid computer auralizations of Byzantine chant, recorded anechoically (with minimal room acoustics). Combining literary analysis, philological inquiry, and scientific research, this study uncovers the multisensory aesthetics of Hagia Sophia and recuperates the notion of aural architecture.

Certain materials and artistic choices went into the making of the sixth-century church of Hagia Sophia in Constantinople to produce a particular aesthetic appearance (Fig. 1). Although no Byzantine texts recorded these aesthetic intentions, this lacuna in the evidence does not mean that no aesthetic program underlay the conceptualization of Hagia Sophia. Rather, an examination of medieval ekphrasis discloses the intent of this artistic production: how the interior looked physically and how it was perceived subjectively. In this paper, I shall draw on ekphrastic texts to extract the aesthetic terms of the artistic conceptualization of the building by specific Byzantine authors and their audiences and to retrieve the sensual and religious effects of its interior on the contemporary beholder.

Recent studies have begun to reveal the performative nature of Byzantine art and how its meaning is created when light and shadow trigger the polymorphy of its surfaces, and when the beholder perceives these exterior changes as animation (*empsychosis*), projecting his or her own sensual experience (*pathema*) on the object.¹ Aesthetic phenomenology, with its focus on the way an object appears and the effect this produces on the spectator, offers a new direction of analysis.² Moving away from treating the image as static and monolithic, this alternative approach uncovers and explores the polymorphic and its impact on the human imagination. A contemporary artwork will serve as an example of the issues engaged by

aesthetic phenomenology. James Turrell's piece of sculpture/architecture *Space That Sees* (1992) is a room without a ceiling, in which the sky appears like a framed painting.³ When clouds pass by or birds fly overhead, they animate the interior and make it perform a "representation" of the sky in front of the viewer that is phenomenal, not pictorial. The object-space thus functions as an imagistic engine, using variable natural phenomena to produce images, while simultaneously stimulating the viewer's imagination. In effect, Hagia Sophia offers a similar performative paradigm: the shimmering surfaces of marble and gold become animate in the shifting natural light, and these transient manifestations trigger the spectator's memory and imagination to conjure up images. Byzantine ekphrasis both documents and sustains this interaction between the real, the perceived, and the imagined. Along with the optical aspect, the vast interior of Hagia Sophia revetted in marble and gold also has an aural dimension in that it produces extremely reverberant acoustics. Rather than keeping the analysis of visual characteristics separate from sonic properties, this study will reunite them, thereby recuperating the idea of aural architecture.

In part literary analysis, philological inquiry, and scientific work, this essay focuses on the psychology of response, especially on the effect polymorphy has on the viewer and how it was culturally and religiously conditioned.⁴ More precisely, the goal of this article is to recover the interior art and architecture of Hagia Sophia as experienced by the visitor in the sixth century. Although a few scholars, such as Liz James, Nadine Schibille, and Nicoletta Isar have anticipated some aspects of my approach, this is the first work to investigate the original phenomenological operations of the interior of Hagia Sophia as an integrated whole, in which sight and sound work together.⁵ It relies on examination of the primary sources that include the well-known ekphrasis of Hagia Sophia by Paul the Silentary to argue that the structure was designed for reverberation. To support and substantiate my intuition that Hagia Sophia was designed to afford the worshiper a multisensory aesthetic experience, I tie aesthetics, etymology, and liturgy into a single interpretation, which is thoroughly documented in the notes.⁶ Since poetry targets the imagination, and the polymorphic surfaces of marble and gold similarly stir the imagistic capacity of the human brain, I purposefully employ poetic language as a way of reconstituting what I think was an interior of shifting



FIGURE 1. *Hagia Sophia, 532–37 and 562, interior* (© Erich Lessing / Art Resource, NY).

appearances produced by the sheen of translucent marble in the lower half of the building and the glitter of gold on the upper half, which worked together to produce a particular effect on the viewer.

For the most part, the scholarly analysis of architecture regards buildings as static entities. Yet an interior of marble and gold creates an environment of shimmer and reflection, and to do it justice, one needs to employ a dynamic medium.⁷ In a radical move, I have resorted to film as a way of recording how the marble and gold changed at such moments of transition as sunrise and sunset.⁸ The time selected is important because Hagia Sophia's interior was meant to be experienced during the Eucharistic liturgy, which coincided with the Byzantine third hour of the day (approximately between sunrise and mid-morning). Yet, because today Hagia Sophia functions as a museum (AyaSofya Müzesi), visitors cannot enter before nine o'clock and are thus prevented from seeing the polymorphy caused by the rising sun. Again, my video is not a reconstruction of the sixth-century interior but a record of how light affects reflective surfaces. It directs the attention of the modern viewer to the ephemeral, which lies at the core of Hagia Sophia's aesthetic. The use of film as a medium recording the process of changing appearances—the subject of aesthetic phenomenology—offers an alternative means for demonstrating the performative character of medieval art.

In similar deictic terms, I used as a soundtrack for the film Byzantine chant digitally imprinted with the room acoustics of Hagia Sophia. This computer model is built on the basis of acoustic data gathered in situ. However, this auralization (the process of imprinting recorded music with the acoustic parameters of a space) should not be taken as a reconstruction of the sixth-century liturgy. Using computer technology makes the humanist suspicious, and rightly so. But let me define the parameters of my use of technology. I employ it to model how a voice unaccompanied by musical instruments sounds in Hagia Sophia based on the current physical conditions of the building.⁹ Just as the architectural historian records and studies the material remains of a building and then proposes a reconstruction, so, too, the acoustician approaches the same material evidence when offering an acoustic model. This auralization is valuable because it gives us the possibility of hearing a baseline acoustics for Hagia Sophia and overcoming a logistical impasse, because, as a secular space, AyaSofya Müzesi does not allow music to be performed or recorded on-site.

This merging of the humanities with exact sciences has been inspired by Deborah Howard and Laura Moretti's *Sound and Space in Renaissance Venice*, a pioneering study of aural architecture and polyphony in Counter-Reformation Venice.¹⁰ The book presents acoustic measurements of twelve Venetian churches gathered in 2006, the in situ recording of St. John's College Choir, Cambridge, in April 2007, and the gathering of subjective responses of the audience and choristers to the acoustics of these interiors. Combining musicology with architectural history, archival work, and modern technology,

the authors put forward the first systematic study correlating qualitative (subjective) with quantitative (objective) acoustic measurements. Embracing Howard and Moretti's methodology, my project similarly merges art historical analysis with research in acoustics and audio recording. It employs visual, textual, and musicological evidence, video, the popping of balloons, the building of acoustic models, auralizations, and the recording of Byzantine chant. In exploring the concept of aural architecture, this article will suggest that Hagia Sophia constitutes an aesthetic totality—optical and acoustic—that reenacts in its architectural fiction the perceptual experience of polymorphy linked in the Byzantine imagination to coruscating water. The aesthetic it maintains has a linguistic basis in the iterative Greek root *marmar-*, connecting *marmaron* (marble), *marmaragma* (gleam, glitter), and *marmairo* (to quiver, sparkle). The onomatopoeic sound of these words and the image of quivering water that they elicit in the listener's imagination will become important in the subsequent analysis of polymorphy and reverberance and their role in the Eucharistic ritual.

The Linkage between Poetry and Aesthetics

Paul the Silentary wrote an ekphrasis of Hagia Sophia recited during the rededication ceremonies held between 24 December 562 and 6 January 563 in the imperial and patriarchal palaces.¹¹ His poetry has been dismissed as a “flowery language” filled with “turgid archaisms,” but it is important to remember that his aristocratic audience was capable of understanding his classicizing style, which was based on Homeric vocabulary and written in hexameter (verses 136–1029) with two prologues in iambic trimeter (verses 1–80 and 81–135).¹² Paul builds his ekphrasis by using highly evocative images tied to the Eucharistic ritual. Modern scholars have noted the richness of visual imagery in Late Antique literature and the prominent role ekphrasis played in it.¹³

Paul describes the materials and surfaces of Hagia Sophia as unstable and shifting in appearance. When he focuses, for instance, on the marble of the banister (*solea*), he calls this particular stone *aiolomorphos*, meaning “changing shape and appearances.”¹⁴ He defines its color through a series of metaphors that bring to mind a variety of natural elements and textures:

... and having an *aiolomorphon* nature it displays a variety (*poikillettai*) in respect to shining (*aigle*). . . . in parts it is seen ruddy (*ereuthos*) mingled with pallor (*ochro*), or the fair brightness (*selas*) of human fingernails; in other places the brilliance turns into a soft wooly whiteness (*argennon*), gently staying or imitating the beauty/sheen (*charin*) of yellow boxwood (*pyxou*) or the semblance of beeswax which men wash in clear mountain streams and lay out to dry under the sun's rays; it turns silver-shining (*argyphon*), yet not completely altering its color, still showing traces of gold.¹⁵

The poetry strings together metaphors, connecting the chameleonic appearance of the stone to the color of dawn, the pallor of death, fingernails, yellow boxwood, and beeswax. In particular, Paul mixes opposites: *ereuthos* (ruddy) with *ochros* (sullen, lifeless).¹⁶ Similarly, wax is malleable and polymorphic; it can be dry, warm, wet, and cold and still remain wax. Washed in the mountain stream, the wax displays the sheen of silver, while retaining specks of gold. The trope of aporia lurks in this profusion of metaphors, yet a similar contrast and opposition are offered by the actual marble in Hagia Sophia. The verses envelop the spectator-hearer in a whirl of dualities of sense perceptions: hard and soft, solid and liquid, wet and dry. Antithesis and synkresis alternate in this string of paraded images. Another feature of the poetry is the effort to capture evanescence, a surface that is translucent and reflective at the same time, shimmering and polychromatic. The language takes on the very character of the phenomenon it describes: it changes in order to depict a polychromatic stone with shifting appearances caused by light.

The terms *polymorphy*, *variety*, and *shimmer* (*poikillo*, *aigle*) point to major aesthetic principles that actually guided the composition of Late Antique literature. Focusing on Latin texts and the tradition of rhetoric as recorded in the *progymnasmata* (manuals for the study of rhetoric), Michael Roberts shows that Late Antique poetry exhibits a marked preference for variation (*varietas* in Latin, *poikilia* in Greek), repetition, chiastic structuring, and jewel effects. Of these, variation is fundamental, leading to the increasing conception of poetry as an imaging text, and this process of visualization concentrates more specifically on the instability and mutability of color.¹⁷ The pairing of variation with the effects of light leads Roberts to coin the expression “jeweled style.”¹⁸ This definition of Latin poetry could easily be applied to the Greek ekphrasis of Paul. In fact, Gianfranco Agosti reaches many of the same conclusions in his analysis of sixth-century Classicism in Greek poetry.¹⁹

Moreover, the jewel effects frequently tap into perceptual experiences. As developed by Stoic epistemology, ekphrasis activates through vivid language (*enargeia*) mental images (*phantasiai*), which are imprints on the soul of sense apprehension.²⁰ The *phantasiai* resurrected by the speaker create in the listener a simulacrum of perception itself, and this process is a perceptual mimesis, as Ruth Webb observes: “it is the act of seeing that is imitated, not the object itself.”²¹ Given its reliance on perceptual mimesis, can the ekphrasis serve as a reliable record for a historical moment of aesthetics or aesthetic experience, or phenomenology? In the past, ekphrasis was sometimes used by twentieth-century art historians in an archaeological/literal way, to mine the text for evidence about the shape of an object or building.²² Recent scholarship, for its part, looks at ekphrasis as a literary style recording a move from the sensible-material characteristics of the object to the intelligible-imaginary realm.²³ Christian ekphrasis, a field that has only recently attracted scholarly attention, by contrast, targets the spiritual operations, which are activated by the symbiosis



FIGURE 2. *Hagia Sophia*, 532–37 and 562, view of the Proconnesian floor and south aisle (© Bissara V. Pentcheva).

of material structure and ritual.²⁴ Gregory of Nyssa, in his homily of St. Theodore the Recruit (which includes an ekphrasis of the martyrium), states: “Therefore, on the basis of what we can perceive, we believe in invisible things and because of what we experience in the world, we believe in the promise of future things.”²⁵ This patristic statement attests to a formulation of mystical experience linking perceptual apprehension with the spiritual. For this reason, I take the scholarly position that ekphrasis of a church building does not function only intertextually, activating a literary tradition, but also integrates a direct response to the sensual materiality of the space and uncovers in it a metaphysical dimension.²⁶ And since this particular church was sheathed in marble and gold, in analyzing Paul’s ekphrasis, I will focus on how glitter, which is linguistically embedded in the root *marmar-* (as in *marmaron*, *marmarygma*, *amarygma*, and *marmairo*), structures the spiritual operations of Hagia Sophia.²⁷

Transitive Terms: Marmaron, Marmara, Marmarygma, and Marmairo

Of great significance for this study is the way in which *marmarygma* is connected to *marmaron* (marble), the Sea of Marmara, and the image of coruscating water (*marmairo*). The marble floor of Hagia Sophia is composed of gray Proconnesian marble, quarried on the island of Proconnesus in the Sea of Marmara, and is divided by four bands of green stone, which were interpreted in the past as the rivers of paradise (Figs. 2 and 3).²⁸ The gray stone is book-matched, meaning the plaques are cut across the veins and arranged in pairs whose pattern creates a continuous wavelike design (Fig. 4). According to ancient geology (Theophrastus, *De lapidibus* [ca. 315–305 BCE], following Aristotle’s *Meteorologia*, Book 3), marble was thought to be composed of earth particles percolated in water and then solidified into stone by dry exhalations from the depths of the earth.²⁹ The association between marble and water grew in the

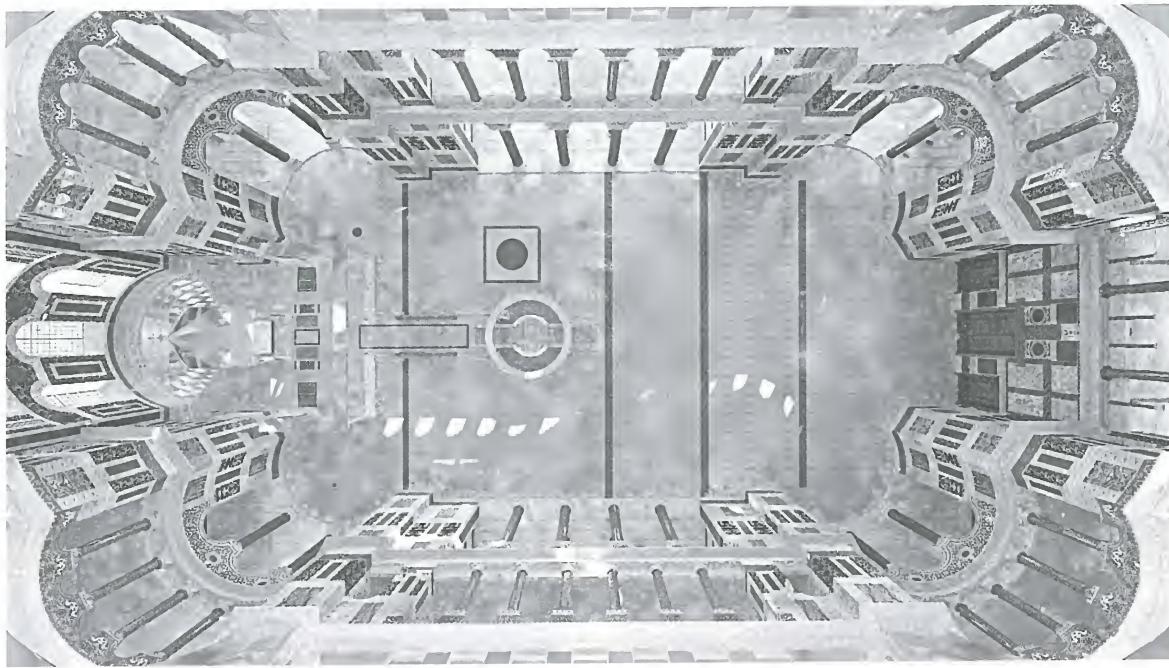


FIGURE 3. *Hagia Sophia, 532–37 and 562, reconstruction of the marble floor seen from above* (© Lars Grobe, Oliver Hauck, Andreas Noback, Rudolf H. W. Stichel, Helge Svensson, Technische Universität Darmstadt).

Late Antique period, and this linkage acquired a greater visual prominence, forming a new aesthetic standard when the dove gray Proconnesian stone replaced the green Carystian marble formerly dominant in the interiors of Roman bathhouses and other public buildings.³⁰ The wave pattern and luminosity of the Proconnesus stone stimulated viewers to conjure up in their imaginations the image of the sea. Moreover, the proximity of the quarries to the capital also encouraged this preference for Proconnesian marble in Constantinople.³¹ While continuing this line of research on the cultural perception of marble, my emphasis falls on how the Proconnesian slabs generate the experience of movement and temporality.

When describing the floor of Hagia Sophia, Paul seeks out and dwells on changing appearances:

The peak of Proconnesus soothingly spreading over the entire pavement / has gladly given its back to the life-giving ruler [Christ/the emperor], / the radiance of the Bosphorus softly ruffling / transmutes from the deepest darkness of swollen waters (*akrokelainiontos*) to the soft whiteness (*argennioi*) of radiant metal (*metallou*).³²

Paul attributes animacy to the island of Proconnesus, willingly spreading its back for the emperor and Christ. Its stone, cut into slabs, forms the floor of the Great Church. Its polished surfaces resemble the radiance given off by the softly ruffling Bosphorus. Here the poet uses the onomatopoeic *phrisousa*, a word containing the sound of the wind. An animate, as opposed to static, image emerges in the poetry, based on the memory of



FIGURE 4. *Hagia Sophia, 532–37 and 562, sunlight glistening on the Proconnesian marble floor* (© Bissara V. Pentcheva).

coruscating water. Its shimmering surface is in constant flux, continually changing its shape. The next line of the poem intensifies this spectacle of shifting, chameleonic appearances; the radiance changes from the deepest darkness of gushing, swollen waters (*akrokelainos*) into the soft whiteness of warm sheep's wool (*argennos*), shining with the radiance of metal (*metallon*).³³ The verse aptly renders the effects of polymorphosis, or *poikilia*. In Paul's ekphrasis, marble acquires the varying appearance of water, transmuting into wool, then into metal. The words evoke an alchemical process, in which stone liquefies into water and molten metal.



FIGURE 5. *Hagia Sophia*, 532–37 and 562, north aisle, sunlight gilding the Proconnesian marble floor (© Bissara V. Pentcheva).



FIGURE 6. *Hagia Sophia*, 532–37 and 562, north aisle, sunlight glistening on the marble revetment (© Bissara V. Pentcheva).

As he calls up the image of the Bosphorus, Paul encourages his audience to dwell on movement and change: water ruffled by winds, light transforming the surface into liquid metal. To an extent, this polymorphy of the Proconnesian marble is still observable today. At dawn the stone glows with the luster of mother-of-pearl that recalls the opalescence of the Bosphorus at certain times of the day (Figs. 5–7). So far, this kinetic aspect of the perceptual images evoked in Late Antique poetry has not been discussed in the scholarship. *Poikilia*, fragmentation, miniaturization, and the jeweled style have been highlighted instead.³⁴ I would like to add to them the concept of *marmar-*, which issues from the image of running or quivering water and conveys the liquefiant, fugitive, and ephemeral in Hagia Sophia. Paul recognizes the polymorphic nature of marble not only in its polychromacy but also in the way its surfaces interact with light. He is attracted to this change and sees a link between it and the image of quivering water. These verses following his description of the Proconnesian floor will prove the point:

The ceiling encompassing gold-inlaid tesserae, / whose pouring down (*chyden*) in glittering (*marmairousa*) gold-streaming (*chrysorrhytos*) ray (*aktis*) / irresistibly bounces off the faces of the faithful.³⁵

The lines bespeak the metamorphosis of solid metal into a river of shimmering gold gliding across reflective marble (Figs. 5, 6, and 8). The flow (*chyde*) of the fluid gold (*chrysorrhytos*) ray (*aktis*) liquefies the ceiling as its shimmer bounces off the faces of the faithful (Figs. 9 and 10).³⁶ Natural light has an animating effect on the interior. At dawn, I have found, the first rays cause the marble revetments to acquire relief (Fig. 6). Similarly, when sunlight falls on the tessellated Proconnesian frames, it transforms them into gilded streams, thus unifying the gold mosaic with the marble (Figs. 5, 6, 8, and 9). This perceptual merging of gold and marble is linguistically enabled



FIGURE 7. A view of the Bosphorus in the morning on 6 December 2010 (© Bissara V. Pentcheva).

by the word *marmairo* (to sparkle, quiver), as the verb again conjures up the image of scintillating water. The shimmer of gold is seen through the metaphor of water. *Marmairo* forms a near-phonetic pair with *marmaron*, *marmaryge*, and *marmarygma* (sparkle), thereby linking these materials and phenomena aurally into one transmuting visual entity.

The Linkage of Marmarygma and Charis: Animation as Empsychosis

The iterative *marmar-* presents the perceived transformation of different materials—light, metal, and stone—into water, and it is this image of water that offers a kinetic dimension to Paul's imagined world. Similarly, in conveying movement, the iterative *marmar-* foregrounds the process that causes inert things to become alive (*empsychos*). We can detect how the concept of liveliness operates by analyzing Paul's most memorable evocation of surging water in his ekphrasis of the ambo

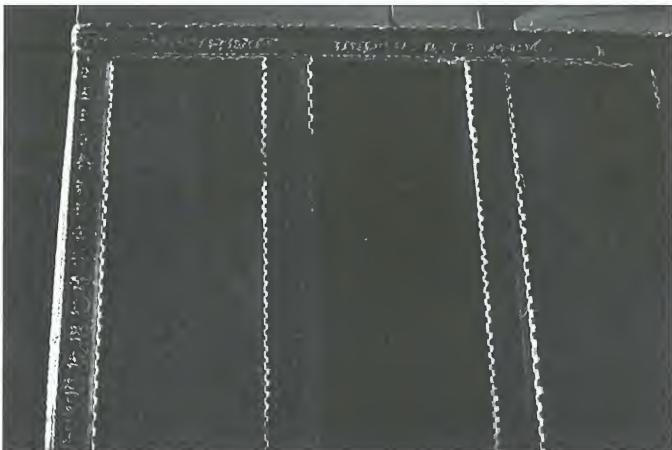


FIGURE 8. *Hagia Sophia, 532–37 and 562, sunlight framing in gold the tessellated marble frames of the revetment* (© Bissara V. Pentcheva).

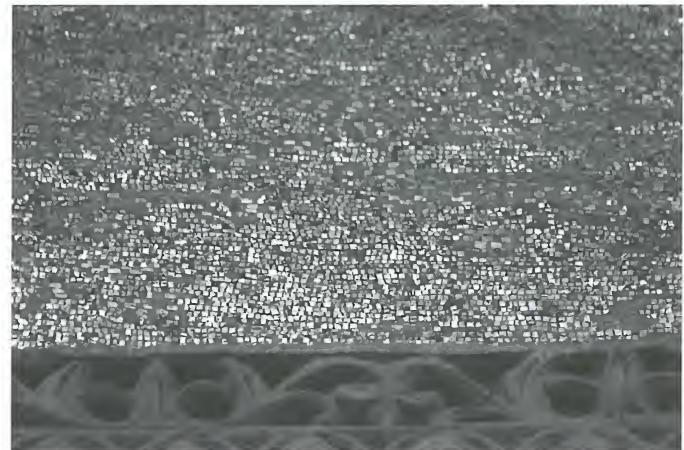


FIGURE 9. *Hagia Sophia, 532–37 and 562, sunlight in a tympanum in the south aisle makes the gold mosaic shimmer* (© Bissara V. Pentcheva).

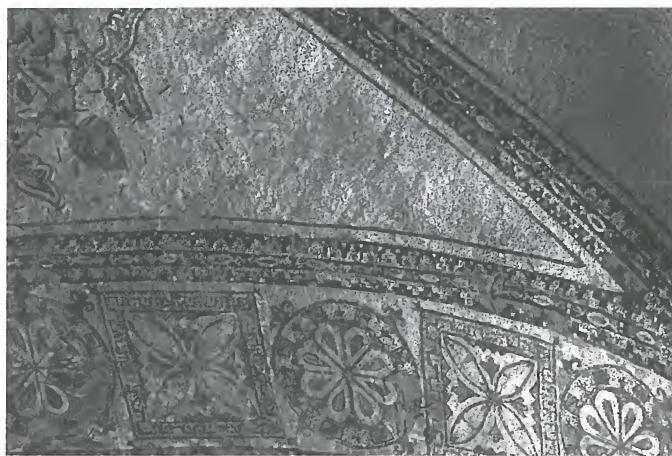


FIGURE 10. *Hagia Sophia, 532–37 and 562, Justinianic gold glass mosaic in the vaulting of the inner narthex* (© Bissara V. Pentcheva).

and *solea*. The power of this scene stems from the merging of perceptual memories with a recollection of the liturgical rite:

And as an island rises amid the waves of the sea . . . , so in the midst of the boundless temple rises upright the tower-like ambo of stone. . . . Here the priest who brings the good tidings passes along on his return from the ambo, holding aloft the golden book; and while the crowd strives in honor of the immaculate God to touch the sacred book with their lips and hands, the countless waves of the surging people break around.³⁷

Paul the Silentary describes the ambo through the metaphor of an island washed by the sea. He expands on this figure of speech by comparing the congregation's pushing forward to reach the Gospel book to that of surging waves. The metaphoric language shifts between the man-made interior and nature outside: floor becomes sea; the pulpit, island; the people, waves.

Animate and inanimate transform into each other. Anthropologists have observed how combining the memory of sensual perception with that of ritual stimulates the most vivid imaginings.³⁸ This is exactly the combination put forward by Paul. The religious zeal and physical energy expended in trying to touch the Gospel book become subsumed in his poetry by the image of breaking waves. His ekphrasis seeks to express dynamism and the life that bursts forth and imbues the inert with movement: the *kymata* (waves) of *kinymenon demon* (moving people). Just like *marmaron*, *marmarygma*, and *marmairo*, the near-phonetic pair of *kyma* and *kinymai* strengthens the power of the metaphor and intensifies the intertwining of animate and inanimate. This phenomenon resembles Alfred Gell's concept of interdigitation, when the subject projects his animacy on the object and thus experiences the latter as alive.³⁹

The image of the breaking waves conveys the process of inspiriting matter, which in turn evokes the Eucharist, a model that his audience understood well. For the Eucharist, in essence, enacts the imparting of spirit into matter, transforming bread and wine into flesh and blood.⁴⁰ *Pneuma* (the Holy Spirit) causes this transformation when it descends in the scent of burning incense over the gifts. In employing terms such as *marmairo* and *marmarygma* and *kyma* and *kinymai*, Paul compels his spectators-hearers to recognize in the changing appearances of marble and gold the presence of vivifying force—the Holy Spirit.

The movement of the waves and the quiver of glittering gold mosaic reflected from the marble floor create an image of a world in flux. To this dynamic of molten metal and sparkling water, Paul adds the image of woods and lush meadows in spring that the marble columns of the naos and the revetments represent, and he seeks in them the manifestation of *empsycho-sis* linking glitter with *charis* (Fig. 11):

In turn four columns firmly resting on the ground lift [the six columns of the gallery] by unshaken force, / with

gilded capitals they stand effusing grace (*charitessi*) / in the shimmer (*amarigmata*) of Thessalian marble. / They separate the airy central performance stage (*kallichoroio*) of the temple under the dome / along the length of the neighboring aisles. / Never in the land of the Molossians did they cut such columns, high-crested, full of grace (*charientas*), blooming (*tethelotas*) in the color harmony of variegated (*daidaleoisi*) forests and flowers.⁴¹

The four Thessalian marble columns appear as trees firmly rooted in the ground. Their gilded capitals please the eye with beauty (*charitessi*) and shimmer (*amarigmata*). While *charis* suggests beauty and grace, it also evokes the memory of the Eucharist with its concomitant descent of *pneuma*.⁴² The glitter of the gilded acanthus in the spandrels stimulates the viewer to see them as animate, and, similarly, the shafts of the columns are filled with energy, perceived in the gleam (*amarigmata*). Speckled with green, gray, and white, the Thessalian columns suggest the perceptual mimesis of polychromatic forests and flowers (*alsesi kai anthesi*). In Greek, “flower” also designates “color.” Consequently, the image of a meadow of flowers is juxtaposed to the dynamic contrast of the shadowy forest; this antithesis has a kinetic dimension.⁴³ *Daidalos*, meaning “complex” or “variegated,” expresses this dynamic multitonality and luster. The colored marble of the columns does not offer an abstract depiction of landscape. Instead, the juxtaposition of shimmer and luminosity stirs the perceptual memory of brightness and shadow: the *amarigmata* (sheen) of *marmaron* infused with the *charis* (grace, beauty) of gold. Roberts, who analyzed this principle of contrast and juxtaposition in Late Antique poetry, also characterizes this literature as a meadow in spring.⁴⁴ His definition is fully justified when we look at Paul the Silentary’s ekphrasis of the marble revetments. His poetry uses marble to construct an image of a landscape filled with contrasting colors.

Paul’s poetry is not alone in intensifying the imagery; the material production itself becomes more lavish in this period. Marble revetments originated in Hellenistic architecture and became prominent in Late Roman Republican buildings, and the trend continued during the Imperial age. With Constantine, marble revetments entered the vocabulary of church architecture.⁴⁵ What makes Hagia Sophia exceptional is the quantity and rich variety of marble used for its interior. Paul engages the perceptual properties of these revetments:

And all the precious [stone] that sprung from Onyx / gleaming with the radiance of gold tesserae (*metallo*) / and that which the land of Atrax produces / in the smooth plains, not the highlands, / in part with the intense green of spring (*chloaonta*) not unlike emerald, / in part from the deep green (*bathymenou chloerou*) appearing almost blue in form (*kyanopidi morphei*); / just like the juxtaposition of snow next to the shimmer (*marmaryges*) of black: / an intertwined *charis* has risen from the stone.⁴⁶

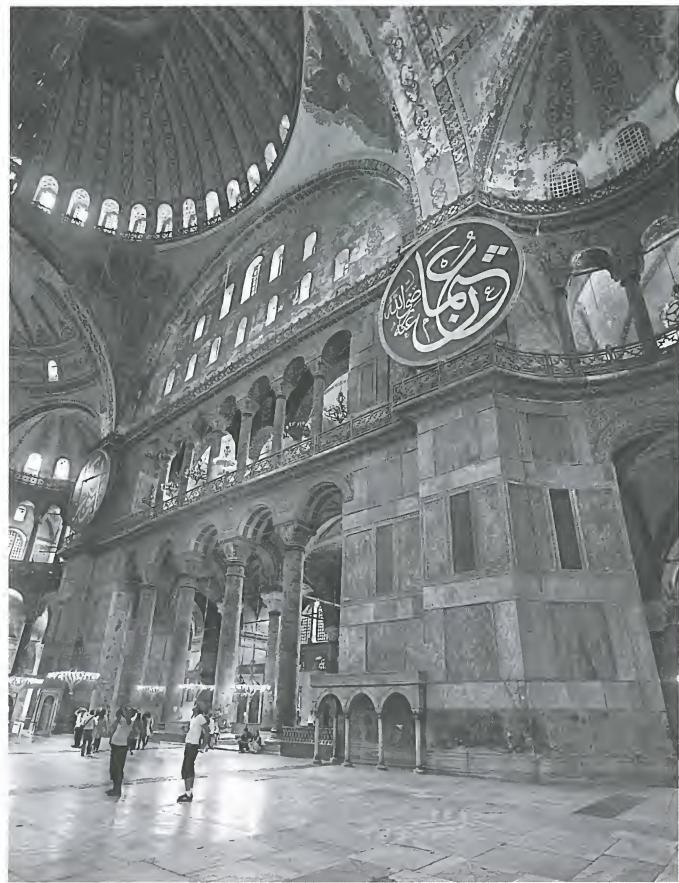


FIGURE 11. Hagia Sophia, 532–37 and 562, naos and south aisle (© Vanni / Art Resource, NY).

The way onyx looks is compared to the radiance of gold tesserae (*metallon*), while the face of the stone from Atrax alternates between the sheen of spring green and a deep green almost resembling dark blue. These lines capture the culturally specific color perception of Byzantium. Rather than hue, color words stress brightness and saturation.⁴⁷ Once again, an intense contrast is sought between the light-reflective and the light-absorptive properties of materials.⁴⁸ The metamorphosis is phenomenal, triggered by ambient changes. The shifts and contrasts express a larger concept, that of the presence of spirit in matter: “an intertwined *charis* has risen from the stone.”

Glitter has a long tradition in Greek literature. Homer uses *marmairo* and *marmaryge* for the sea and the sparkling appearance of metal armor.⁴⁹ Nonnos of Panopolis in the early fifth century triples the use of *marmairo* and *marmaryge*, writing about light, metal, and the gifts of the sea. Most frequently, however, he uses the terms to capture the sparkle of the eyes, showing how glitter becomes a marker of the soul and thus an outer expression of liveliness.⁵⁰ Nonnos offers a bridge between Homer and Paul, explaining the metaphysical turn in the perception of glitter: *marmarygma* marks the animation of matter. Rather than naturalistic figurations, the marble floor and walls

as well as the gold mosaic perform through their polymorphy the presence of *pneuma* in matter.⁵¹

In an influential article on the marbles of Hagia Sophia, John Onians has argued that the Late Antique viewer, trained in the culture of *ekphrasis* and *encomium* (praise), was capable of discovering naturalistic images in increasingly abstract visual representations.⁵² Onians credits the increased role of *ekphrasis* for this development of imagistic capabilities that allowed viewers to conjure up naturalistic anthropomorphic forms from the abstract figuration of veined marble. He explains: “the imaginative response of the spectator created a new imaginative activity in the artist. The same is even truer of the relationship between the modern artist and his public, with both exploring the frontier of imaginative alertness. Now, as then, the real measure of that alertness is the capacity to see representational reference in what is essentially abstract.”⁵³ Linking medieval abstraction to modern art, Onians believes that *ekphrasis* helped viewers to imagine pictorial representation in the marble slabs.

I would like to propose an alternative interpretation. Abstraction in modern art is characterized by a desire to break away from naturalistic representation. This concept does not apply to nonfigurative medieval art. Rather than using the imagination to see representation in what is abstract, the medieval viewer wanted to see the presence of the spirit in what is essentially changing appearances of matter such as glitter or shadow (Figs. 4–6, 8–10).⁵⁴ As Gregory of Nyssa stated, sense perception is a means of reaching the spiritual.⁵⁵ Hagia Sophia’s interior presents a synergy between two forces that produce the effect of animation: first, the imaging power of such forms and materials as columns and wave-pattern book-matched marble slabs; and, second, the phenomenal polymorphy of these surfaces. Faced with both, the viewer simultaneously could conjure images of quivering water based on his/her perceptual experience and tie them to the concepts of *charis* and *empsychosis*.

Georges Didi-Huberman’s interpretation of the fictive marbles painted by Fra Angelico in S. Marco, Florence, may be put in parallel with our study. Indeed, his approach highlights the capacity of nonanthropomorphic figuration to trigger mental images.⁵⁶ What distinguishes my analysis of marble from Didi-Huberman’s is the recognition of the role of such natural phenomena as shimmer that trigger observers to view the inanimate as animate. Materiality, in the Byzantine model, has the potential under certain conditions to be perceived as alive. In using reflective materials such as gold and marble, the interior of Hagia Sophia acts like an iridescent shell; sun rays, shadows, and drafts of air moving across its surfaces activate or cancel the display of *marmarygma*. The temporality of these phenomenal shimmers and moving shadows conveys the ephemeral descent of *pneuma*, or, to use Paul the Silentary’s words, a *charis* emanating from the stone.⁵⁷ Byzantine animation is performative and objectively nonrepresentational; it is steeped in a material production that uses reflective and translucent surfaces and in the spectacle of *ekphrasis* and liturgy.

The Sound of Marmaron: The Scientific Study of Hagia Sophia’s Acoustics

The optical *marmarygma* issuing from the marble also has an acoustic correlate. Marble reflects most of the energy of sound waves hitting it back into the surrounding space. This phenomenon together with the immense volume of Hagia Sophia result in extremely reverberant acoustics.⁵⁸ What follows is an excursus in the scientific study of sound in Hagia Sophia, revealing what methods and computer technologies have been used and how the results could be integrated into the larger study of aesthetics.

The experience of listening to sound is as much a function of what the source emits as it is about the space in which sound propagates. When a sound is made by a source in a room, an acoustic wave is produced, which propagates in all directions. The sound first heard at the listener’s position is called the “direct sound.” As other portions of the propagating wave front interact with obstacles along the way, some of their energy is absorbed by those obstacles and some is reflected back into the space. This reflected energy reaches the listener’s position slightly later, and these delayed arrivals are called “early reflections.” As the sound reflections continue to be reflected by the surfaces and obstacles in the room, their staggered arrivals create the “late field reverberation.” The sound will continue to be reflected until all the energy is absorbed by the air and the objects in and boundaries of the space. The staggered arrivals and different energies of the direct sound, the early, and the late field reverberations enable the listener to perceive the imprint of space on sound. This imprint is called the “Impulse Response” (IR), and the process of imprinting a space on a sound is called “convolution” or “auralization.”⁵⁹ Both technical terms, IR and auralization, will feature widely in my discussion.

The spatial imprint on sound indicates an important psychological dimension of aural architecture, more specifically, that a piece of music can have varying effects on the listener depending on the space in which it is performed.⁶⁰ This is the case with Hagia Sophia and Byzantine chant. The huge marble-revetted interior is reverberant and quickly mixes the reflected sound energy, especially at the wavelengths in the range of the human voice; it stays full and well mixed for the long reverberation time of about ten seconds. The chanting, which triggers this aural experience, uses the human body as an instrument, thus further implicating the corporeal experience of architecture and the synergy and interaction between the faithful and the mass of reflective *marmaron*.

Studies of the acoustics of Hagia Sophia began in 2003, when the Danish group of Christoffer Weitze, Jens Rindel, Claus Christensen, and Anders Gade, using three sound sources and twelve receivers, measured a standard reverberation time (RT_{30})⁶¹ in Hagia Sophia at about ten seconds for a sound source in the apse, and slightly more than eleven seconds for a sound source in the space under the dome when the church is empty.⁶² The long reverberation time is a result of the immense interior,

which is more than 70 meters in length and 55 meters in height, with a total volume of 255,800 m³, all enclosed in reflective surfaces of marble and gold mosaic.⁶³ This long reverberation time remains uniform across a vast spectrum of frequencies in the range of the singing human voice, from 200 Hz–4,000 Hz (Hz=Hertz, a unit of frequency equal to one cycle per second).⁶⁴ In comparison with modern concert halls, whose reverberation time is often less than two seconds, Hagia Sophia's exhibits a particularly long resonance.⁶⁵

The Danish research revealed that the dome and conches, because of their parabolic surfaces, reflect high-frequency waves and focus sound directly down to the space under the dome.⁶⁶ The current cupola, dating to 562, has a steeper apex, so the focus is higher above the floor. By contrast, the original flat dome of 537 would have lowered this focus, better projecting the reflections back to the people gathered underneath it. Clarity and intelligibility of speech are poor overall, even in the space under the dome.⁶⁷ The Danish group then placed the measured acoustic data in a computer model created by the software Odeon® developed by Rindel and Christensen to produce predictive room acoustics. Together with the musicologist Christian Troelsgaard, the engineers offered auralizations of Byzantine chant and Qur'anic readings.⁶⁸ Although they measured sound on-site, they used a computer model generated by Odeon® to convolve studio recording of music with the acoustic parameters of Hagia Sophia ("to convolve" or "to auralize" denotes the process of imprinting a space on a recorded sound).

Stanford University's "Icons of Sound" Project and Cappella Romana

The Danish project inspired me to seek a collaboration with Jonathan Abel, a consulting professor at Stanford's Center for Computer Research in Music and Acoustics, because I was interested in the phenomenological aspects of sound, more specifically, in the difference between the experience of a melody recorded with minimal room acoustics versus one imprinted with the resonant matrix of Hagia Sophia. What could be the psychoacoustic response to the reverberant as opposed to the anechoic sounds? To experiment with imprinting room acoustics on recorded music (auralization), one needs to measure the Impulse Response of Hagia Sophia. And because the Danish group did not publish an IR, we had to obtain one by gathering acoustic data in situ.

Abel developed a new method of measuring and reproducing room acoustics by recording the sounds of balloons popping. Balloons are inexpensive and easy to use. When they explode, they produce a simple but compact acoustic pulse, which radiates rather uniformly and contains the entire frequency range of human hearing. Knowing how a space imprints itself on a simple pulse enables us to study and reproduce more complex processes such as human speech or singing, which may be thought of as being composed of a series of pulses.

In May and December 2010, we recorded four balloons popping in Hagia Sophia with the balloon under the dome and the listener both under the cupola and in the west end. The information from one of the resulting wave forms is plotted as a spectrogram image on the axes of time and frequency, with color (grays in the black-and-white figure) representing the intensity of sound (Fig. 12). Several reflections likely came from the dome and are visible in the background of diffuse arrivals, which in turn probably came from the colonnades. Over time, the acoustic energy in the space became well mixed, and the response took on a smooth, noiselike character as the balloon's energy slowly decayed. A second graph presents the impulse response as a wave form (Fig. 13).⁶⁹ The spectrogram shows the ten-second reverberation as a function of frequency on a logarithmic, nonlinear time axis, because the logarithmic corresponds to human perception (Fig. 14).⁷⁰ The curve rises and plateaus at a ten-second reverberation time for frequencies between 150 Hz and 1,000 Hz (the range of human speech and singing). This "hat" shape is an acoustic feature displayed by some of the best concert halls today, whose interiors, too, sustain the longest reverberation for the mid-frequencies.⁷¹ Yet, in contrast to the modern concert hall, clarity in Hagia Sophia is poor for listeners positioned away from the source, and the reverberation can overwhelm the direct sound, rendering speech unintelligible.⁷²

Abel then used the Impulse Response of Hagia Sophia to convolve an existing recording of the *Cheroubikon* with Hagia Sophia's late field reverberation.⁷³ In the process, he developed a new method of convolving anechoic performance with an Impulse Response derived directly from in situ balloon-pop measurements.⁷⁴ As a result, the new auralizations are based on the sound pulse recorded in Hagia Sophia, and not entirely synthesized using a computer software (like Odeon® or CATT®) that assigns relative values to materials and architectural shapes.

Subsequently, Abel and I collaborated with Cappella Romana, a choir specializing in early music, and recorded their performance of Romanos Melodos' First *Kontakion* on the Nativity, the *Prokeimenon* of St. Basil, and Psalm 140. In this way we produced new anechoic recordings, which we convolved with the Impulse Response of Hagia Sophia. During the recording session, the voice of each singer was captured on a separate track, dry (with minimal room acoustics imprinted on the recorded sound). Each chorister received live feedback via earphones, auralizing his or her performance in Hagia Sophia. This real-time experience enabled the singers to hear themselves sing in the Great Church during the recording session, as opposed to an effect introduced during postproduction.⁷⁵ This new approach helped the singers interact live with the immense interior of *marmaron* and align their pitch with the maximum resonance of the building. As a result, they dramatically slowed their tempo. Abel's use of simultaneous auralization marks a departure from the traditional method and offers a potential for future studies in psychoacoustics.⁷⁶

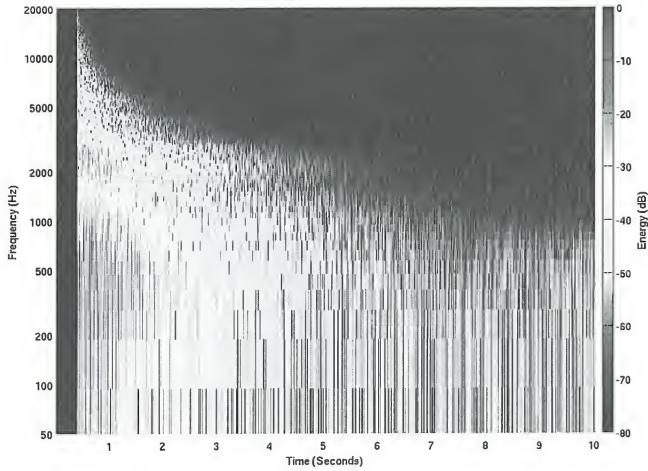


FIGURE 12. Spectrogram of a balloon popping in Hagia Sophia (© Jonathan Abel).

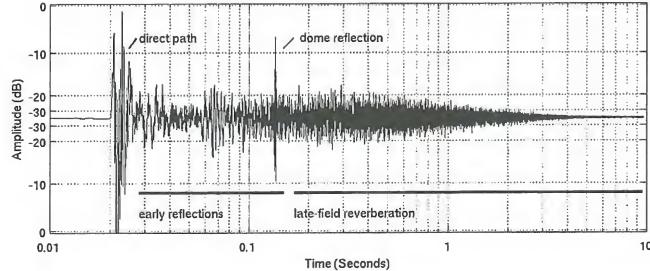


FIGURE 13. The reverberation time (T_{30}) plotted as a wave form (© Jonathan Abel).

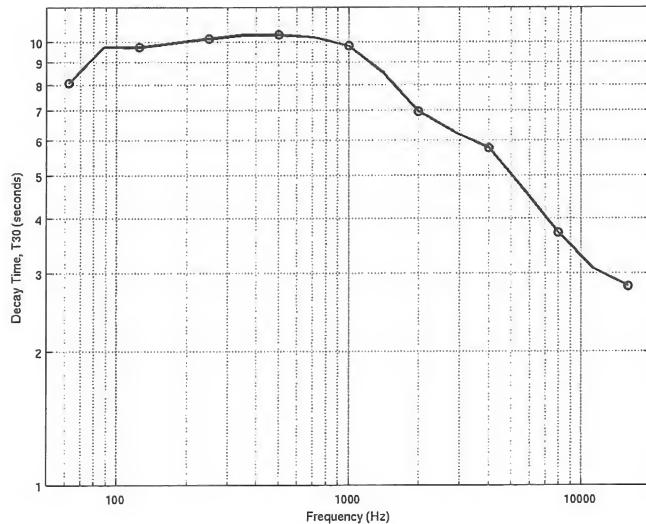


FIGURE 14. A graph of the reverberation time (T_{30}) as a function of frequency (© Jonathan Abel).

We tested our recording method at Stanford University's Memorial Church, which has floors of marble and cork, a dome, and gold mosaic. Here Abel recorded one singer in situ. Then he measured an Impulse Response by popping a balloon

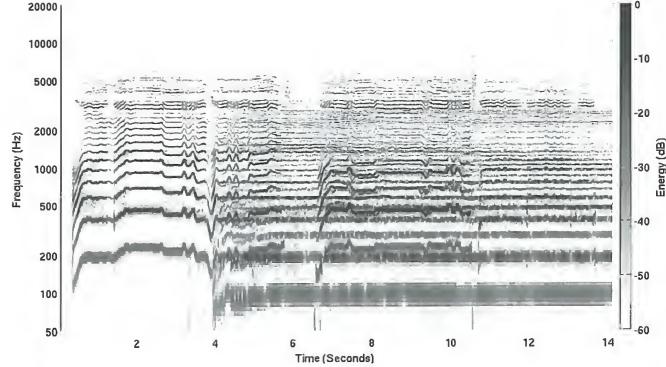


FIGURE 15. Spectrogram of the solo and drone performance of an excerpt of the Prokeimenon sung anechoically (© Jonathan Abel).

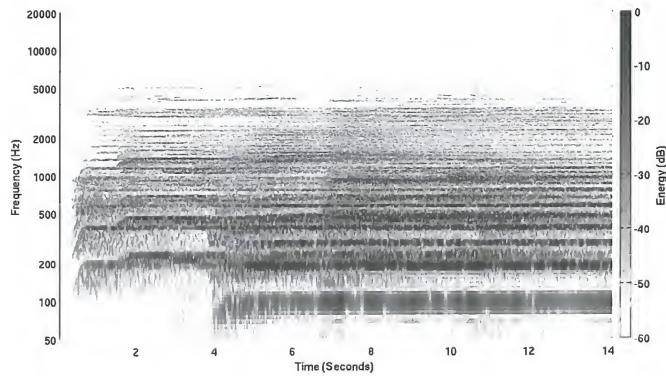


FIGURE 16. Spectrogram of the solo and drone performance of an excerpt of the Prokeimenon auralized in Hagia Sophia (© Jonathan Abel).

where the singer had stood. He then recorded the same chanter anechoically in a studio and convolved this recording with the measured Impulse Response. The auralization was found to be sonically very similar to the recorded live performance in Memorial Church.

A comparison of two spectrograms from the anechoic recording and the Hagia Sophia auralization clearly demonstrates the resonant acoustics of the Great Church (Figs. 15 and 16). Both graph the first few seconds of the soloist, John Boyer, and Cappella Romana performing a *Prokeimenon*, or gradual for the feast of St. Basil. In the dry performance, one could clearly see how the soloist's voice peaks at about 200 Hz, triggering harmonics ranging between 300 and 5,000 Hz. The drone (*ison*) hovers around 100 Hz, with harmonics reaching to 2,000 Hz and above (Fig. 15). When the same performance is auralized in Hagia Sophia (reproducing the acoustics for the empty interior), it is enhanced and enriched, with the acoustic energy lingering and harmonized with the new notes produced in the space (Fig. 16). The spectrogram shows how the reverberant acoustics of Hagia Sophia bring about a smoothing effect and flesh out the fullness of sound.

Since the scientific study of Hagia Sophia reveals its resonant acoustics, it is important to ask if reverberation was a

design consideration for the architects Anthemius of Tralles and Isidorus of Miletus or a by-product of an architectural tradition using large quantities of marble and many domes and semidomes. This question is impossible to answer because of the lack of written evidence.⁷⁷ The sixth-century Byzantine sources describe the two designers of Hagia Sophia as *mechanikoi* or *mechanopoioi* (engineers). Anthemius was a mathematician with an interest in conic structures, ellipses, and mirrors. Since reverberation is about reflected acoustic energy, it is plausible that Anthemius' interest in mirrors contributed to the design of a reverberant interior. Similarly, Isidorus, a professor of geometry and mechanics who edited mathematical texts and wrote treatises, was concerned with inscribing solids in other solid shapes, vaulting, and the design of a special compass for the drawing of parabolas.⁷⁸ The plan and orientation of the building and the shape of the dome demonstrate exact knowledge of ancient science.⁷⁹ The nave of Hagia Sophia takes the form of a solid enclosed within a solid. The same paradigm is manifested in the smaller-scale precedents of the church SS. Sergius and Bacchus (527–32) and the concurrent church of St. Irene (532–37).⁸⁰ These structures suggest a trend to develop a space free of columns at the center but enclosed in an ambulatory.⁸¹ Such an interior will create diffused reflections, suffusing unpleasant echo.

Did the sixth-century visitor recognize the reverberant acoustics of Hagia Sophia? This question also cannot be answered because of the lack of direct textual evidence. Yet the concepts of a powerful reverberant voice hovering over a soundscape of marble is present in Paul the Silentary's ekphrasis: "Who would sing with thundering voices the sounds of Homer, the marble meadows solidly assembled along the walls or the well-formed pavement of the hauntingly high naos?"⁸² Paul connects the perception of a thundering sound with Hagia Sophia's immense interior and marble revetments. His rhetorical question, "Who would sing," highlights the acoustic interaction between the human voice and material surfaces, imitating in this way the synergy between the viewer and optical *marmarygma* stirred by ambient light. Are Paul's words just intertextual tropes? Clearly they evoke Homer, the model Paul emulated in his hexameter form and the *Odyssey* travel structure. But what the verse also conjures is the vision of an aural architecture and a transcendent voice.

The Embodiment: Singing, Breath, and Holy Spirit

Reverberation time in the range of ten to eleven seconds is extremely long. Not only does it make recitative speech unintelligible, but it also affects singing by causing strong dissonant effects. The church full of people will be far less reverberant than the empty interior (in our computer auralizations), since the sounds will not reflect from the hard surface of the floor (Fig. 17). Similarly, some of the energy of sound waves will be consumed by the textiles of interior furnishings and the bodies and clothing of the spectators. When people moved, their

clothing also produced the sound of rustling, whose acoustic dimension would have contributed to the overall aesthetic of *marmar-*. Through this synergy of body and space, the interior became a better instrument for the human voice, assisting the singing of simple monodic chant. Not surprisingly, such singing defines the character of the Byzantine cathedral liturgy. The service, known as "the sung office," or *asmatike akolouthia*, included antiphonal chanting of psalms with refrains and prayers, which reaches back to fourth-century practices in Jerusalem and Antioch.⁸³ It is also important to note that in the sixth century there was no daily celebration in Hagia Sophia; instead, services took place in this interior only at Saturday vespers and Sunday matins and on major feasts such as Christmas and Easter.⁸⁴ The two weekly services thus incorporated the times of sunrise and sunset in their temporal dimension by celebrating the Eucharist in the third hour of the day, which coincides with light coming from the east and maximum *marmarygma* in the sanctuary, stimulating the faithful to link in their imagination physical light with the descent of the Holy Spirit.⁸⁵

Reconstructing the sound of the *asmatike akolouthia* is a complex problem. The deciphering of musical notation only reaches back to the Middle Byzantine period. Thus, we do not have a written basis on which to reconstruct the sixth-century musical arrangement. What we do know, however, is that choral refrains were chanted in the singing of the psalms⁸⁶ and in the *kontakion*, or sung sermon, which emerged in roughly the same period.⁸⁷ Similarly, the new *Cheroubikon* hymn, sung during the Eucharist procession, might have involved the entire congregation.⁸⁸

Once inside Hagia Sophia, a soloist known as a *domestikos* probably ascended the ambo to sing from there the opening and the refrain. The professional choir, *psaltai*, standing under the ambo and possibly the *anagnostes* (readers) positioned in the space between the sanctuary and the ambo then began to chant the psalm responsorially, meaning they were divided into two groups and sang in alternating fashion verse by verse.⁸⁹ When one group chanted the poetic line, the other held the drone and vice versa. At the end of each verse, the congregation joined in with the refrain.

The *Cheroubikon* hymn was a more complex production designed specifically for the Great Entrance of Hagia Sophia and officially incorporated in its liturgy in 573–74.⁹⁰ In the course of its singing, two corteges proceeded to meet: the clergy with the oblation from the west, and the emperor from the east.⁹¹ The performance of this hymn might have included the entire congregation.⁹² The *Cheroubikon* starts by explicitly recalling the previous visions of the divinity in Isaiah, Ezekiel, and Revelation: "We who mystically represent (*eikonizontes*) the cherubim and sing the thrice-holy hymn to the life-giving Trinity, let us lay aside all worldly care [Luke 21:34] to receive the King of All escorted unseen by the angelic corps. Alleluia, alleluia, alleluia."⁹³ The hymn asks the participants in the rite to imagine the actual ecclesiastical cortege as a host of angels, intertwining the terrestrial with a vision of heaven. The sung

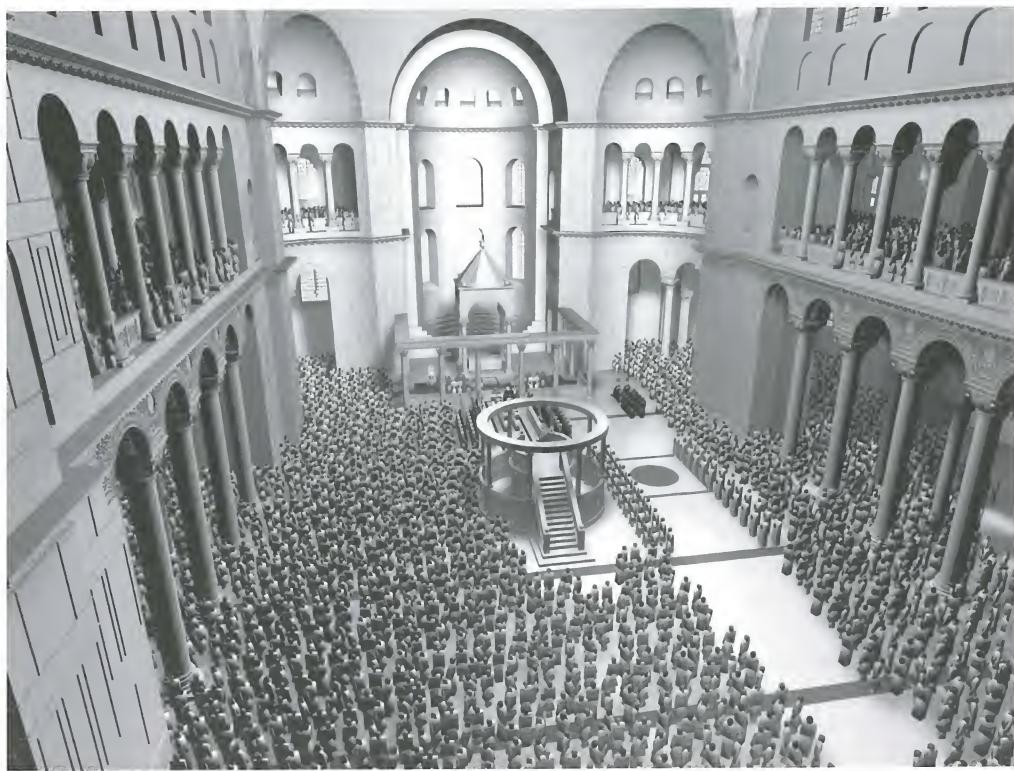


FIGURE 17. *Hagia Sophia, reconstruction of the Justinianic liturgy unfolding in the interior* (© Lars Grove, Oliver Hauck, Martin Kim, Andreas Noback, Rudolf H. W. Stichel, Helge Svensson, Technische Universität Darmstadt).

text invites the participants to perceive their action in space as a “representation” (*eikonizontes*). But what is also clear is that its visual dimension is combined with an aural one. We might not have a historical record to reconstruct the sixth-century musical setting of this hymn, but we do know what the room acoustics of this interior are (measured for an empty interior devoid of liturgical furnishings and textiles). The vast naos ensures a long initial delay (the time between the arrival of the direct sound to the recorder-hearer and the arrival of early reflection), lowering the intimacy of sound and creating the mimetic effect of being lost in an immense container.⁹⁴ The psychoacoustics of this distant, nonintimate kind of sound could be perceived in metaphysical terms. Since the hymn was originally composed for the Justinianic interior of Hagia Sophia, its text and its sound were imprinted by the optical and acoustic properties of this space. A Middle Byzantine commentary of the *Cheroubikon* states: “When the singers perform that hymn together with the people, it is signifying that also the angels sing together in the highest.”⁹⁵ In the act of performance, human bodies become “representations” of the angelic host. Just as the nonobjective figuration of the marble produced images in the imaginations of the spectators, or the phenomenal *marmarygma* of marble and gold was seen as a marker of animation, so, too, the reverberant sound produced by singing the *Cheroubikon* compelled its performers to perceive the totality of their bodies in space as icons, like *marmaron*, reflecting divine figuration.

To grasp this process of perceived animation, it is important to explain the range of meanings of *pneuma* in Greek. The word signifies the “Holy Spirit,” which is sensorially manifested in the scent and smoke of burning incense.⁹⁶ *Pneuma* also denotes human breath and concomitantly human chant.⁹⁷ Thus, the experience of indwelling spirit could be manifested optically, aurally, and olfactorily: *pneuma* as breeze, incense, smoke, and breath. Its multisensorial energy is activated in the Eucharistic liturgy through the burning of incense, the oblation procession, chanting, and, finally, the consumption of the bread and wine transformed into the body and blood of Christ.

The reverberant acoustics of Hagia Sophia transform the human voice into an emanation, no longer focused on the intelligibility of words but on their sensual perception.⁹⁸ The reflective interior and its immense volume manipulate the spectator to experience the Logos (Word/Christ) in the bodiless voice of sound reflections. Only film studies have addressed this phenomenon, calling it the *acousmêtre* and defining it as the voice behind the screen with no face or body to be seen that could be taken as the source of the sound. The perception of *acousmêtre* in film has a menacing and threatening effect, which is due to the visual absence of the source.⁹⁹ By contrast, the Byzantine *acousmêtre* as realized in Hagia Sophia is salvific and luminous, manifested as an acoustic and optical *marmarygma*. As bodies and clothing trap some of the sound waves, consuming their energy, the faithful corporeally partake in the *acousmêtre*.¹⁰⁰ In

this way, *pneuma* is perceived as reentering mortal flesh. Rather than threatening, the bodiless voice of Hagia Sophia offers a return to dwelling in the divine by the consumption and recovery of spirit. In this inspiriting/*empsychosis* process, the faithful are transformed back into *eikones tou theou*: “icons of God” in the model of Adam. Whereas in Genesis 2:7 God breathes life into Adam, animating his inert flesh, in Hagia Sophia a reversal happens. Human breath emptied as chant becomes a reverberant sound perceived as a divine *acousmêtre* and consumed by bodies and clothing.

Conclusion

In exploring the way objects and spaces appear and the way they affect the spectator, phenomenology as a new method in art historical analysis has the potential to transform the field of medieval studies. It is especially applicable to Byzantine art, which exhibits an artistic tradition invested in polymorphy and an aesthetic response, recorded in epigrams and ekphrasis, showing the awareness of phenomenal light and shadow as a manifestation of animation. *Poikilia* and *marmarygma* are just two examples of the terms that structure Byzantine aesthetics. Seeing and hearing the shimmer of *marmaron* led the faithful to recognize the presence of *pneuma* in the exteriority of optical and aural reflections. It is also important to acknowledge that

visual *marmarygma* is caused by an external factor, a ray of light from the sun or an oil lamp. By contrast, aural *marmarygma* is generated internally by the singer: breath exhaled by the mouth and sound energy partially consumed by the body and drapery. In this distinction between sight and hearing, we can detect a Byzantine hierarchy of the senses implied by Hagia Sophia’s interior and ritual. The closer this gradation of sensual perception reaches to the spiritual, the more, paradoxically, it strives toward greater bodily investment. The faithful move from the mirror reflections of sight to the consumed energy of sound, to climax with the sweet taste of the body and blood of Christ at the Eucharist.

Our modern scholarly discourse falls short of the intensity and complexity of this multisensory experience. Reaching out to film and computer auralization has enabled me to mobilize new media to convey aspects of Hagia Sophia’s performative aesthetics and the psychological effect they exercised on the spectator. Yet the saturated phenomenon at the core of its space and ritual is built on the principle of excess: a multisensory experience tied in Byzantium to the theurgical concept of *empsychosis*.¹⁰¹ Hagia Sophia plunges the faithful into a sea ruffled by human breath transformed into divine reverberation, beguiling them to approach the harbor of the Eucharist, where the faithful recuperate *pneuma* and ephemerally transform into *eikones* of God.

NOTES

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4. On connotative meanings of a work of art, R. Barthes, "Rhetoric of the Image," in *Semiotics: An Introductory Anthology*, ed. R. Innis (Bloomington, IN, 1985), 190–205.
5. L. James, "Sense and Sensibility," *AH*, 27/4 (2004), 523–37. N. Schibille, "Astronomical and Optical Principles in the Architecture of Hagia Sophia in Constantinople," *Science in Context*, 22 (2009), 27–46. N. Isar, "Chorography (*chora, choros*)—a Performative Paradigm of Creation of Sacred Space in Byzantium," in *Hierotopy: The Creation of Sacred Spaces in Byzantium and Medieval Russia*, ed. A. Lidov (Moscow, 2006), 59–90; eadem, "Choros: Dancing into the Sacred Space of Chora," *Byzantium*, 75 (2005), 199–224; eadem, "Choros of Light: Vision of the Sacred in Paul the Silentary's Poem *Descriptio S. Sophiae*," *Byzantinische Forschungen*, 28 (2004), 215–42; and eadem, "The Dance of Adam: Reconstructing the Byzantine *choros*," *Byzantinoslavica*, 61 (2003), 79–204. On geometry, mathematics, and engineering, see I. Potamianos and W. Jabi, "Interactive Parametric Design and the Role of Light in Byzantine Churches," *Proceedings of the eCAADe 2006: Communicating Space(s)*, ed. V. Bourdakis and D. Charitos (Volos, 2006), 798–803; and W. Jabi and I. Potamianos, "Geometry, Light, and Cosmology in the Church of Hagia Sophia," *International Journal of Architectural Computing*, 5/2 (2007), 305–19. H. Svenshon and R. Stichel, "'System of Monads' as Design Principle in the Hagia Sophia: Neo-Platonic Mathematics in the Architecture of Late Antiquity," in *Nexus VI: Architecture and Mathematics*, ed. S. Duvernoy and O. Pedemonte (Turin, 2006), 111–20; V. Hoffmann, *Der geometrische Entwurf der Hagia Sophia in Istanbul* (Bern, 2005), reviewed by M. Dennert in *Sehepunkte*, 6/7–8 (2006), and by R. Oosterhout in *JSAH*, 65 (2006), 435–37; and A. Cutler, "Structure and Aesthetic at Hagia Sophia in Constantinople," *Journal of Aesthetics and Art Criticism*, 25 (1966), 27–35. W. MacDonald, "Roman Experimental Design," 3–15, and S. Ćurčić, "Design and Structural Innovation," 16–38, both in *Hagia Sophia from the Age of Justinian to the Present*, ed. R. Mark and A. Çakmak (Cambridge, 1992). H. Buchwald, "Saint Sophia, Turning Point in the Development of Byzantine Architecture?" in *Die Hagia Sophia in Istanbul: Bilder aus sechs Jahrhunderten und Gaspare Fossatis Restaurierung der Jahre 1847 bis 1849*, ed. V. Hoffmann (Bern, 1999), 29–58.
6. The Byzantine phenomenon recalls the Wagnerian concept of *Gesamtkunstwerk*. R. Wagner, *The Art Work of the Future and Other Works*, trans. and ed. W. W. Ellis (Lincoln, NE, 1993). B. Millington, *The New Grove Guide to Wagner and His Opera* (Oxford, 2006), 151–52; J. Koss, *Modernism after Wagner* (Minneapolis, 2010); A. Finger and D. Follett, eds., *The Aesthetics of the Total Artwork: On Borders and Fragments* (Baltimore, 2011); and M. Vidalis, "Gesamtkunstwerk," *Architectural Review*, 30 June 2010, at <http://www.greekarchitects.gr/en//gesamtkunstwerk-id3185> (accessed 10 March 2012).
7. On the experience of architecture through movement, see A. Schmarsow, "The Essence of Architectural Creation," read in 1893, published in *Empathy, Form, and Space: Problems in German Aesthetics, 1873–1893*, trans. and intro. H. Mallgrave and E. Ikonomou (Los Angeles, 1992), 281–97.
8. <http://iconosofsound.stanford.edu/aesthetics.html>.
9. On the value of auralizations, A. Farina and R. Ayalon, "Recording Concert Hall Acoustics for Posterity," 24th AES (Audio-Engineering Studies) Conference on Multichannel Audio, Banff, Canada, 26–28 June 2003, at <http://www.ramsete.com/Public/AES-24/183-AES24.PDF> (accessed 16 May 2010).
10. D. Howard and L. Moretti, *Sound and Space in Renaissance Venice* (New Haven, 2010). On aural architecture, see also V. Zara, "Musica e Architettura tra Medio Evo e l'Età Moderna: Storia Critica di un'Idea," *Acta Musicologica*, 77 (2005), 1–26.
11. *Johannes von Gaza, Paulus Silentarius und Prokopios von Gaza: Kunstsbeschreibungen justinianischer Zeit*, ed. P. Friedländer (Leipzig, 1912; rpt. Hildesheim, 1969), hereafter Paul the Silentary, *Descriptio S. Sophiae*, and idem, *Descriptio ambonis*. English trans. of verses 136–1029 by C. Mango, *Art of the Byzantine Empire, 312–1453: Sources and Documents* (Toronto, 1986), 80–96; and the prologue and conclusion trans. by P. Bell, *Three Political Voices from the Age of Justinian: Agapetus, Advice to the Emperor, Dialogue on Political Science, Paul the Silentary, The Description of Hagia Sophia* (Liverpool, 2009), 189–212. French trans., M.-C. Fayant and P. Chuvin, *Description de Sainte-Sophie de Constantinople* (Paris, 1997); Italian trans., M. Fobelli, *Un Tempio per Giustiniano: Santa Sofia di Costantinopoli e la "Descrizione" di Paolo Silenzario* (Rome, 2005). On the performance of Paul's ekphrasis, see M. Whitby, "The Occasion of Paul the Silentary's Ekphrasis of S. Sophia," *Classical Quarterly*, 35/1 (1985), 215–28; R. Macrides and P. Magdalino, "The Architecture of Ekphrasis: Construction and Context of Paul the Silentary's Poem on Hagia Sophia," *Byzantine and Modern Greek Studies*, 12 (1988), 47–82. K. Dark and J. Kostenc, "A New Archaeological Study of Hagia Sophia, Istanbul," in *Proceedings of the 22nd International Congress of Byzantine Studies, Sofia, 22–27 August 2011*, ed. I. Iliev, 3 vols. (Sofia, 2011), 3:213–37.
12. Paul the Silentary, *Descriptio S. Sophiae*, verses 617–20. G. Agosti, "Niveaux de style, littérarité, poétiques: Pour une histoire du système de la poésie classicante au VIe siècle," in *Doux remède: Poésie et poétique à Byzance, Dossiers byzantines*, 9, ed. P. Odorico et al. (Paris, 2009), 99–119; Bell, *Three Political Voices*, 16; Fobelli, *Un Tempio per Giustiniano*, 9, 13n2. G. Downey, *Constantinople in the Age of Justinian* (Norman, OK, 1960), 147–64, esp. 159. On audience response, see Al. Cameron, "Poetry and Literary Culture in Late Antiquity," in *Approaching Late Antiquity*, ed. S. Swain and M. Edwards (Oxford, 2004), 327–54. "Turgid archaisms" in G. Majeska, "Notes on the Archeology of St. Sophia at Constantinople: The Green Marble Bands on the Floor," *DOP*, 32 (1978), 299–308.
13. R. Webb, *Ekphrasis, Imagination and Persuasion in Ancient Rhetorical Theory and Practice* (Farnham, 2009), 85–130; eadem, "The Aesthetics of Sacred Space: Narrative, Metaphor and Motion in *Ekphrasis* of Church Buildings," *DOP*, 53 (1999), 59–74; G. Agosti, "Immagini e Poesia nella Tarda Antichità: Per uno Studio dell'Estetica Visuale della Poesia Greca fra il III et il VI Sec. d.C.," *Incontri Triestini di Filologia Classica*, 4 (2004–5), 351–74. J. Elsner, "The Rhetoric of Buildings in the De Aedificiis of Procopius," in *Art and Text in Byzantine Culture*, ed. L. James (Cambridge, 2007), 33–57.
14. *A Greek-English Lexicon*, ed. H. G. Liddell and R. Scott (Oxford, 1996 with suppl. 1968), s.v. *aiolomorphos*, "of changeful form."
15. Paul the Silentary, *Descriptio ambonis*, verses 79–80 and 84–92, trans. in Mango, *Sources and Documents*, 92, with my amendments:

καὶ φύσιν αἰολόμορφον ἔχων ποικίλεται αἴγλη.
 ἔστι δὲ πῆι μὲν ἔρευθος ἴδειν κεκερασμένον ὄχρωι,
 πῆι δὲ καλὸν βροτέοιστ σέλας στονύχεστιν ὄμοιον.
 ὅλοθι δ' ὄρμηθεσα πρὸς ἀργεννὸν σέλας αἴγλη,
 ἡρέμα μιμνάζουσα, χάριν μιμήσατο πύξον
 ἡὲ μελισσήντος ἐπίρατον εἰκόνα κηροῦ,
 ὃν καθαράς προχοήσι βροτοὶ νίζοντες ἐρίπναις
 πολλάκι τερσαίνουσιν ὑπ' ἡελιώτιδας αὐγάς:
 δὲ μεταίστησε μὲν ἐς ἄργυρον, εἰσέτι δ' οὕπω
 τρέψεν ὅλην χροιὴν ἔτι λείψανα χρύσεα φαίνων.

16. On *ochros*, L. James, *Light and Color in Byzantine Art* (New York, 1996), 51.

17. M. Roberts, *The Jeweled Style: Poetry and Poetics in Late Antiquity* (Ithaca, NY, 1989), 38–65. On the perception of color in Byzantium as brilliance rather than hue, James, *Light and Color in Byzantine Art*.

18. Roberts, *The Jeweled Style*, 55.

19. Agosti, “Niveaux de style, littérarité, poétiques”; and idem, “Immagini e Poesia nella Tarda Antichità.”

20. Webb, *Ekphrasis, Imagination and Persuasion*, 107–30; and V. Platt, “Viewing, Desiring, Believing: Confronting the Divine in a Pompeian House,” *AH*, 25/1 (2002), 87–112.

21. Webb, *Ekphrasis, Imagination and Persuasion*, 107–30, esp. 127–28, relying on E. Scarry, *Dreaming by the Book* (New York, 1999), 6. On the active role of the listener in the creation of meaning, see W. Iser, “The Reading Process: A Phenomenological Approach,” in *Reader-Response Criticism: From Formalism to Post-Structuralism* (Baltimore, 1980), 50–69.

22. For a critique of this approach, W. J. T. Mitchell, *Iconology: Image, Text, Ideology* (Chicago, 1986); and R. Webb and L. James, “‘To understand ultimate things and enter secret places’: Ekphrasis and Art in Byzantium,” *AH*, 14/1 (1991), 1–17.

23. S. Bann, *True Vine: On Visual Representation and the Western Tradition* (Cambridge, 1989); J. Heffernan, *Museum of Words: The Poetics of Ekphrasis from Homer to Ashberry* (Chicago, 1993); W. J. T. Mitchell, *Picture Theory: Essays on Verbal and Visual Representation* (Chicago, 1994); S. Goldhill and R. Osborne, eds., *Art and Text in Ancient Greek Culture* (Cambridge, 1994); J. Elsner, ed., *Art and Text in Roman Culture* (Cambridge, 1996); J. Elkins, *On Pictures and the Words That Fail Them* (Cambridge, 1998); the essays edited and introduced by J. Elsner in *Ramus*, 31 (2002); L. James, ed., *Art and Text in Byzantine Culture* (Cambridge, 2007); Webb, *Ekphrasis, Imagination and Persuasion*; M. Squire, “Making Myron’s Cow Moo? Ekphrastic Epigram and the Poetics of Simulation,” *American Journal of Philology*, 131 (2010), 589–634; idem, “Reading a View: Poem and Picture in the Greek Anthology,” *Ramus*, 39 (2010), 73–103. I thank Jaš Elsner for these references.

24. Webb, “The Aesthetics of Sacred Space,” 68–69. V. Limberis, *Architects of Piety: The Cappadocian Fathers and the Cult of the Martyrs* (Oxford, 2011), 53–96, esp. 61, 63, 65. Webb and James, “‘To understand ultimate things and enter secret places.’” C. Kaesser, “The Body Is Not Painted On: Ekphrasis and Exegesis in Prudentius’s *Peristephanon 9*,” *Ramus*, 31 (2002), 158–74. Unlike the pagan material, research in the field of ekphrasis of a Christian church is in its initial stages. Therefore, my comments here are just preliminary.

25. Gregory of Nyssa, “De Sancto Theodoro,” Migne PG, 46, 736–48, esp. 740: Διὰ τοῦτο πιστεύωμεν ἐκ τῶν φαινομένων τοῖς ἀσφάτοις, ἀπὸ τῆς ἐν τῷ κόσμῳ πείρας τῇ τῶν μελλόντων ἐπαγγελίᾳ. English trans. in J. Leemans et al., eds., *Let Us Die That We May Live: Greek Homilies of Christian Martyrs from Asia Minor, Palestine, and Syria* (London, 2003), 86 and discussed in Limberis, *Architects of Piety*, 61.

26. Libanios described how his fourth-century rival, Bemarchios, recycled a previously composed ekphrasis of a church for another occasion. The lack of apparent correspondence between the speech and the current surrounds resulted in his audience being thrown into confusion. Libanios, *Autobiography*, Book 41, in A. F. Norman, ed., *Libanius: Autobiography and Selected Letters*, LCL (Cambridge, MA, 1992), 102–3; and Webb, “The Aesthetics of Sacred Space,” 62.

27. The same approach is used in the context of Classical Greek sculpture; see R. Neer, *The Emergence of the Classical Style in Greek Sculpture* (Chicago, 2010).

28. Majeska, “Notes on the Archaeology of St. Sophia.”

29. D. E. Eichholz, *Theophrastus De Lapidibus* (Oxford, 1965); and R. Halley, *Le problème des métaux dans la science antique* (Paris, 1974). F. Barry, “Walking on Water: Cosmic Floors in Antiquity and the Middle Ages,” *AB*, 89/4 (2007), 627–56, esp. 631–32.

30. W. R. Lethaby, “On Pavements Like the Sea,” in *Architecture, Mysticism and Myth* (1892; rpt. New York, 2004), 201–20. Barry, “Walking on Water,” 631–32; and H. Maguire, *Earth and Ocean: The Terrestrial World in Early Byzantine Art* (University Park, PA, 1987).

31. Barry, “Walking on Water,” 627, 632–42. Majeska, “Notes on the Archaeology of St. Sophia.”

32. Paul the Silentary, *Descriptio S. Sophiae*, verses 664–67:

πᾶν δὲ πέδον στορέασσα Προκονήσιο κολώνη
ἀσπασίων ὑπέθηκε βιαρκεῖ νῶτον ὀνάσσην·
τρέμα δὲ φρίσσουσα διέπρεπε Βοσπορίς αἴγλη
ἀκροκελαινιώντος ἐπ’ ἀργεννοῖ μετάλλου.

33. On *poikilia* in Homer, G. Nagy, *Homer the Preclassic*, Sather Classical Lectures, 67 (Berkeley, 2010), 273–310. *Poikilia* in Late Antiquity and Byzantium, Roberts, *The Jeweled Style*, 44–65; and Agosti, “Immagini e Poesia nella Tarda Antichità.” Pentcheva, “The Performative Icon,” 644–48; and eadem, *The Sensual Icon*, 139–43.

34. Agosti, “Immagini e Poesia nella Tarda Antichità”; Roberts, *The Jeweled Style*, 44–65; and J. Elsner, “Late Antique Art: The Problem of the Concept and the Cumulative Aesthetic,” in Swain and Edwards, *Approaching Late Antiquity*, 271–309.

35. Paul the Silentary, *Descriptio S. Sophiae*, verses 668–70:

Χρυσεοκολλήτους δὲ τέγος ψηφῖδας ἔέργει,
ῶν ἀπὸ μαρμάρουσα χύδην χρυσόρυτος ἀκτᾶς
ἀνδρομέοις ἀτλητος ἐπεσκίρτησε προσώποις.

36. P. Cesaretti and M. Fobelli, *Procopius: Santa Sofia di Costantinopoli: Un Tempio di Luce (De aedificiis I,1,1–78)* (Milan, 2011), 120–22, 127–31.

37. Paul the Silentary, *Descriptio ambonis*, verses 224, 229–30, 247–51, trans. Mango, *Art of the Byzantine Empire*, 95–96:

Ως δὲ θαλασσαίσιον ἐν οἴδμαστι νῆσος ὀνίσχει, . . .
οὕτω ἀπιερεσίοι κατ’ ἔνδια μέσσα μελάθρου
λάεσι πυργωθεὶς ἀναφαίνεται ὅρθιος ἄμβων, . . .
ἔνθεν ὑποτροπάδην χρυσέν εὐάγγελος ἀνήρ
βίβλον ἀερτάζων διανίσσεται. ιεμένης δὲ
πληθύος, ἀχράντοι θεοῦ κατὰ μύστιδα τιμήν,
χειλεα καὶ παλάμας ιερήν περὶ βίβλον ἐρεῖσαι,
κύματα κινυμένων περιάγνυται ἄσπετα δήμων

38. M. Johnson, “Reflection, Reality Monitoring, and the Self,” in *Mental Imagery*, ed. R. Kunzendorf (New York, 1991), 3–16. R. Finke, *Principles of Mental Imagery* (Cambridge, MA, 1989); and G. Lakoff, *Women, Fire and Dangerous Things: What Categories Reveal about the Mind* (Chicago, 1987). R. Langacker, *Foundations of Cognitive Grammar* (Stanford, 1987).

39. A. Gell, *Art and Agency: An Anthropological Theory* (Oxford, 1998), 116–22.

40. Pentcheva, *The Sensual Icon*, 36–56.

41. Paul the Silentary, *Descriptio S. Sophiae*, verses 542–50:

τοὺς δὲ χαμαιπαγέες πίσυρες μεγάλοισι [κα]ρήνοις
κίονες ὀγλίζουσιν ὑπ’ ἀστυφέλικτον ἀνάγκην
χρυσόκομοι χαρίτεσσι κατήροβ[ι], ήται
Θεσσαλίδος πετρης ἀμαρύγματα: μέσσα δὲ νηοῦ
ἔνδια καλλιχόροιο διακρίνουσιν ἐδέθλων
γείτονος αἰθούσης περιμήκεος. οὐ ποτε τοίους
κίονας ἐτμῆσαντο Μολοσσίδος ἐνδοθι γαίης,
ύψιλόφους, χαρίεντας, ἐύχλοιας ἄλσεσι[
ἄνθεσι δαιδαλέοισι τεθηλότας.

42. T. Torrance, *The Doctrine of Grace in the Apostolic Fathers* (London, 1948; rpt. Grand Rapids, MI, 1960), 139–41. S. Duffy, *The Dynamics of Grace: Perspectives in Theological Anthropology* (Collegeville, MN, 1993), 27–42; and *Oxford Dictionary of Byzantium*, ed. A. Kazhdan (Oxford, 1991), 1:863–64, s.v. *charis*.

43. On kinetic geometry, Gonzalez, *Beauty and Islam*, 83–88.

44. Roberts, *The Jeweled Style*, 55.

45. A. Kleiner, *Die Inkrustation der Hagia Sophia: Zur Entwicklung der Inkrustationschemata im römischen Kaiserreich* (Münster, 1979), 45–93.

46. Paul the Silentary, *Descriptio S. Sophiae*, verses 640–46:

ὅσσα τ' Ὄνυξ ἀνέτη διαυγάζοντι μετάλλῳ
ώχριστων ἐρίτημα, καὶ Ἀτρακίς δπόσα λευροῖς
χθῶν πεδίοις ἐλόχευσε καὶ οὐχ ὑψαύχενι βήσστη,
πῆπι μὲν ἄλις χλοάσοντα καὶ οὐ μάλα τῆλε μαράγδου,
πῆπι δὲ βαθυνομένου χλοεροῦ κυανώπιδι μορφῆι·
ἥν δέ τι καὶ χιόνεσσιν ἀλίγκιον ἄγχι μελαίνης
μαρμαρυγῆς, μικτὴ δὲ χάρις συνεγέρτε πέτρου.

47. James, *Light and Color in Byzantine Art*; L. James, “Color and Meaning in Byzantium,” *Journal of Early Christian Studies*, 11/2 (2003), 223–33; R. Franses, “When All That Is Gold Does Not Glitter,” in *Icon and Word: The Power of Images in Byzantium: Studies in Honor of Robin Cormack*, ed. A. Eastmond and L. James (Aldershot, 2003), 13–24; E. Schwarzenberg, “Colour, Light and Transparency in the Greek World,” in *Medieval Mosaics: Light, Color, Materials*, Villa I Tatti / Harvard University, Center for Italian Renaissance Studies, 17, ed. E. Borsook et al. (Milan, 2000), 15–34. Cesaretti and Fobelli, *Procopius: Santa Sofia di Costantinopoli*, 122–26.

48. Franses, “When All That Is Gold Does Not Glitter.”

49. Homer, *Iliad*, Book 12, verse 195 (armor); Book 13, verses 22 (golden palaces) and 801 (bronze); Book 14, verse 273 (the shimmering sea); Book 16, verses 279 (armor), 664 (harness), and 735 (stone); Book 17, verse 594 (bronze); Book 18, verses 480 (the rim of the shield) and 617 (armor); and Book 23, verse 27 (harnesses of bronze). Homer, *Odyssey*, Book 8, verse 265 (twinkling of dancing feet); and Book 9, verse 499 (rock). On *marmaree* and *porphyry*, see Nagy, *Homer the Preclassic*, 273–310. Neer, *The Emergence of the Classical Style*, 76–77.

50. Nonnos of Panopolis, *Dionysiaca*, trans. W. Rouse, ed. L. Rind, and intro. H. Rose, LCL, 3 vols. (Cambridge, MA, 1955–56). A search in Thesaurus Linguae Graecae (TLG; <http://www.tlg.uci.edu/>) shows more than sixty entries ranging from descriptions of stone, water, sparkling eyes, face, light, and metal.

51. Pentcheva, *The Sensual Icon*, 128–38.

52. J. Onians, “Abstraction and Imagination in Late Antiquity,” *AH*, 3 (1980), 1–23; and J. Trilling, “The Image Not Made by Hands and the Byzantine Way of Seeing,” in *The Holy Face and the Paradox of Representation*, Villa Spelman Colloquia, 6, ed. H. Kessler and G. Wolf (Bologna, 1998), 109–28.

53. Onians, “Abstraction and Imagination in Late Antiquity,” 23.

54. Pentcheva, *The Sensual Icon*, 45–56, 121–54.

55. Gregory of Nyssa, “De Sancto Theodoro,” trans. Leemans et al., *Let Us Die That We May Live*, 86; and Limberis, *Architects of Piety*, 61 (see n. 25 above).

56. G. Didi-Huberman, *Fra Angelico: Dissemblance and Figuration*, trans. J. M. Todd (Chicago, 1995), 22–101.

57. Pentcheva, *The Sensual Icon*, 121–54; eadem, “Moving Eyes,” 222–32; and Gell, *Art and Agency*, 116–22.

58. W. Sabine (1868–1919), the father of modern acoustics, established the correlation between materials and volume; E. Thompson, *The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America* (Cambridge, MA, 2002), 3–4, 33–45.

59. A. Gade, “Acoustics in Halls for Speech and Music,” in *Springer Handbook of Acoustics*, ed. T. Rossing (New York, 2007), 301–50. B. Blessler and L.-R. Salter, *Spaces Speak, Are You Listening? Experiencing Aural Architecture* (Cambridge, MA, 2007), 1–9; and Thompson, *The Soundscape of Modernity*, 2–3.

60. J. Neuhoff, “Ecological Psychoacoustics: Introduction and History,” in *Ecological Psychoacoustics*, ed. Neuhoff (San Diego, 2004), 1–13, I thank Miriam Kolar for bringing this study to my attention. D. Howard and J. Angus, *Acoustics and Psychoacoustics* (Amsterdam, 2009). E. Zwicker and H. Fastl, *Psychoacoustics: Facts and Models*, Springer Series in Information Sciences (Berlin, 2007).

61. Standard Reverberation Time (RT_{30}) is the time it takes for a sound in a reverberant space to die away to inaudibility, based on the rate of decay experienced by sound after it has decayed 30 dB (decibels) from its initial amplitude. Gade, “Acoustics in Halls for Speech and Music,” 307–8; Howard and Moretti, *Sound and Space in Renaissance Venice*, 219; and <http://www.winmls.com/2004/help/reverbetimesrt60.htm> (accessed 3 June 2010).

62. C. Weitze, J. Rindel, C. Christensen, and A. Gade, “The Acoustical History of Hagia Sophia Revived through Computer Simulation,” at www.odeon.dk/pdf/ForumAcousticum2002.pdf (accessed 7 April 2009), and <http://www.odeon.dk/acoustics-ancient-church-hagia-sofia> (accessed 26 April 2010).

63. R. Shankland and H. K. Shankland, “Acoustics of St. Peter’s and Patriarchal Basilicas in Rome,” *Journal of the Acoustical Society of America*, 50/2 (1971), 389–96, esp. 392, 395. Weitze et al., “The Acoustical History of Hagia Sophia Revived through Computer Simulation.” E. Antoniades remarked on a special place in the *solea* where the reverberation was particularly prolonged; Antoniades, *Ekphrasis tes Hagias Sophias, etoi melete synthetike kai analytike hypo apopsin architektoniken, archaiologiken kai historiken tou polythryletou temenous Konstantinoupoleos*, 3 vols. (Leipzig, 1907), 1:108.

64. For a sound source in the apse, see the measurements released at <http://www.odeon.dk/acoustics-ancient-church-hagia-sofia>. For a sound source in the space under the dome (*kallichoros*), see Weitze et al., “The Acoustical History of Hagia Sophia Revived through Computer Simulation.”

65. L. Beranek, *Concert Halls and Opera Houses: Music, Acoustics, and Architecture* (New York, 2004), 21, 29.

66. Shankland and Shankland, “Acoustics of St. Peter’s and Patriarchal Basilicas in Rome,” 392, 395. E. Tzekakis, “Reverberation Time in the Rotunda of Thessaloniki,” *Journal of the Acoustical Society of America*, 57/5 (1975), 1207–9; D. Baumann, “Musical Acoustics in the Middle Ages,” *Journal of Early Music*, 18/2 (1990), 199–210, esp. 203, 208.

67. The speech transmission index STI (0=completely unintelligible, 1=perfect intelligibility) is very low; a sound source set in the east end of the apse has poor intelligibility in the nave under the dome, at STI 0.3–0.4, and is unintelligible in the aisles and galleries, with an STI below 0.2. Similarly, the high T_s values (Center Time, time of the center of gravity of the squared impulse response) measured indicate poor clarity; see <http://www.odeon.dk/acoustics-ancient-church-hagia-sofia>.

68. <http://www.odeon.dk/byzantine-hymns-churches-constantinople> (accessed 20 April 2011). For an excellent discussion of Qur’anic reading and acoustics of the Ottoman mosques, see N. Ergin, “The Soundscape of Sixteenth-Century Istanbul Mosques Architecture and Qur’an Recital,” *JSAH*, 67/2 (2008), 204–22.

69. J. Abel et al., “Estimating Room Impulse Responses from Recorded Balloon Pops,” *Audio Engineering Society 129th Convention* (November 2010), at <http://www.aes.org/e-lib/browse.cfm?elib=15594>.

70. P. Huang et al., “Reverberation Echo Density of Psychoacoustics,” *Audio Engineering Society*, 2008, <http://www.aes.org/e-lib/browse.cfm?elib=14735>; and <https://ccrma.stanford.edu/courses/318>

/mini-courses/rooms/mus318_Abel_Lecture/echo%20density.pdf (accessed 13 March 2012).

71. Beranek, *Concert Halls and Opera Houses*, 21, 29.
72. Abel et al., “Estimating Room Impulse Responses from Recorded Balloon Pops.”
73. The Greek choir of Lycourgos Angelopoulos sings the hymn according to Gregorios Protopsaltes’ (1778–1821) musical setting in the refectory of Fontevraud’s monastery, *The Divine Liturgy of St. John Chrysostom*, Greek Byzantine Choir, dir. Lycourgos Angelopoulos, OPS 30-78. On Gregorios Protopsaltes, see A. Lingas, “Gregorios the Protopsaltes,” at *Oxford Music Online*, <http://www.oxfordmusiconline.com/subscriber/article/grove/music/52232> (accessed 12 March 2010).
74. Abel et al., “Estimating Room Impulse Responses from Recorded Balloon Pops.”
75. <http://iconosofsound.stanford.edu/auralization.html>.
76. Neuhoff, “Ecological Psychoacoustics.”
77. The majority of acoustics research focuses on Western architecture, *Acoustics of Worship Spaces: Presented at the 106th Meeting of the Acoustical Society of America, San Diego, 7–11 November 1983*, ed. D. Lubman and E. Wetherill (New York, 1985); P. Grueneisen, *Sound-space: Architecture for Sound and Vision* (Basel, 2003); P. Vergo, *That Divine Order: Music and the Visual Arts from Antiquity to the Eighteenth Century* (London, 2005); E. Cirillo and F. Martellotta, *Worship, Acoustics, and Architecture* (Brentwood, Essex, UK, 2006); J. Anderson, D. Howard, and L. Moretti, *Architettura e Musica nella Venezia del Rinascimento* (Milan, 2006); Blessler and Salter, *Spaces Speak, Are You Listening?* 67–126; and Howard and Moretti, *Sound and Space in Renaissance Venice*. On architecture and the senses, see J. Pallasmaa, *The Eyes of the Skin: Architecture and the Senses* (Chichester, 2005), 67–126.
78. Schibille, “Astronomical and Optical Principles in the Architecture of Hagia Sophia,” 27–46; R. Ousterhout, *The Master Builders of Byzantium* (Princeton, 1999), 44; Al. Cameron, “Isidore of Miletus and Hypatia: On the Editing of Mathematical Texts,” *Greek, Roman, and Byzantine Studies*, 31 (1990), 103–27, esp. 122; Cutler, “Structure and Aesthetic at Hagia Sophia,” 27–35; Huxley, *Anthemius of Tralles: A Study of Later Greek Geometry* (Cambridge, MA, 1959), 1–43; G. Downey, “Byzantine Architects and Their Methods,” *Byzantium*, 18 (1948), 99–118, esp. 112–14. See also S. Cuomo, *Technology and Culture in Greek and Roman Antiquity* (Cambridge, 2007), 131–64.
79. Svenshon and Stichel, “‘System of Monads’ as Design Principle in Hagia Sophia”; Hoffmann, *Der geometrische Entwurf der Hagia Sophia in Istanbul*; Schibille, “Astronomical and Optical Principles in the Architecture of Hagia Sophia”; Potamianos and Jabi, “Interactive Parametric Design”; Jabi and Potamianos, “Geometry, Light, and Cosmology in the Church of Hagia Sophia”; and I. Potamianos, “The Mathematics of the Ideal Dome,” in Proceedings of the Dresden International Symposium of Architecture, ed. R. Weber and M. Amann (Mammendorf, 2004), 66–72.
80. R. Mainstone, *Hagia Sophia: Architecture, Structure and Liturgy of Justinian’s Great Church* (London, 1988), 149–217; W. Müller-Wiener, *Bildlexikon zur Topographie Istanbuls* (Tübingen, 1977), 112–17 (St. Irene), 177–83 (SS. Sergius and Bacchus); J. Badrill, “The Church of Sts. Sergius and Bacchus in Constantinople and the Monophysite Refugees,” *DOP*, 54 (2000), 1–11; H. Svenshon and R. Stichel, “Neue Beobachtungen an der ehemaligen Kirche der Heiligen Sergios und Bacchos (Küçük Ayasofya Camisi) in Istanbul,” *Istanbuler Mitteilungen*, 50 (2000), 389–409; T. Papacostas, “The Medieval Progeny of the Holy Apostles: Trails of Architectural Imitation across the Mediterranean,” in *The Byzantine World*, ed. P. Stephenson (New York, 2010), 386–405; A. Thiel, *Die Johanneskirche in Ephesos* (Wiesbaden, 2005), 37–48; and J. Alchermes, “Art and Architecture in the Age of Justinian,” in *The Cambridge Companion to the Age of Justinian*, ed. M. Maas (Cambridge, 2005), 343–75.
81. S. Ćurčić, “Design and Structural Innovation.”
82. Paul the Silentary, *Descriptio S. Sophiae*, verses 617–20:

Καὶ τίς ἐριγδούποιστι χανῶν στομάτεσσιν Ὄμήρου
μαρμαρέους λειμῶνας ἀστλισθέντας ἀείσει
ἡλιβάτου νησοῦ κραταιπαγέας περὶ τοίχους
καὶ πέδον εὐρυθέμειλον.
83. O. Strunk, “The Byzantine Office at Hagia Sophia,” *DOP*, 9–10 (1956), 175–202; R. Taft, *The Great Entrance: A History of the Transfer of Gifts and Other Pre-Anaphoral Rites of the Liturgy of St. John Chrysostom* (Rome, 1975); and A. Lingas, “Sunday Matins in the Byzantine Cathedral Rite: Music and Liturgy” (Dissertation, University of British Columbia, Vancouver, 1996). On the stationary character of the liturgy, see J. Baldovin, *The Urban Character of Christian Worship: The Origins, Development and Meaning of Stational Liturgy*, Orientalia Christiana Analecta, 228 (Rome, 1987). *Le Typikon de la Grand Église*, Orientalia Christiana Analecta, vols. 165, 166, ed. J. Mateos, 2 vols. (Rome, 1962–63). M. Aranz, *L’Eucologio Costantinopolitano agli Inizi del Secolo XI* (Rome, 1996).
84. Mateos, *Le Typikon de la Grand Église*, 1:146–59. Johannes Skylitzes, *Synopsis Historiarum*, Corpus Fontium Historiae Byzantinae, 5, ed. I. Thurn (Berlin, 1973), Constantine IX, section 29, verses 19–26, p. 423, discussing how only in the eleventh century did the donation of emperor Constantine IX Monomachos (r. 1042–56) enable the celebration of the liturgy seven days a week. N. Oikonomides, “The Mosaic Panel of Constantine IX and Zoe in St. Sophia,” *Revue des études byzantins*, 36 (1978), 219–32.
85. Jabi and Potamianos, “Geometry, Light, and Cosmology,” 307; V. Grumel, *Traité des études byzantines. I. La chronologie* (Paris, 1958), 163–65; and Downey, *Constantinople in the Age of Justinian*, 114, 127.
86. Strunk, “The Byzantine Office at Hagia Sophia.”
87. E. Wellesz, *A History of Byzantine Music and Hymnography* (Oxford, 1949; rpt. 1961), 179–97. J. Grosdidier de Matons, *Romanos le Mélode et les origines de la poésie religieuse à Byzance* (Paris, 1977). For Romanos Melodos’ kontakia, see *Sancti Romani Melodi Cantica, Cantica Genuina*, ed. P. Maas and C. Trypanis (Oxford, 1963).
88. Taft, *The Great Entrance*, 53–118; Strunk, “The Byzantine Office at Hagia Sophia”; D. Conomos, *Byzantine Trisagia and Cheroubika of the Fourteenth and Fifteenth Centuries: A Study of the Late Byzantine Liturgical Chant* (Thessaloniki, 1974), 31–41, 121–260; and N. Moran, *The Ordinary Chant of the Byzantine Mass*, Hamburger Beiträge zur Musikwissenschaft, 12, 2 vols. (Hamburg, 1975), 1:96–123.
89. A *novella* or stipulation of Justinian sets the number of *psaltai* at 25, and that of *anagnostes* at 110. The latter increased to 160 by the time of Herakleios (r. 610–41). Only half of the two choirs perform at a given occasion (135 at the time of Justinian, 185 at the time of Herakleios); Lingas, “Sunday Matins,” 43–44.
90. Cedrenus, *Historiarum Compendium*, ed. I. Bekker, 2 vols. (Bonn, 1838–39), 1:685.
91. W. Schneider and R. Stichel, “Der ‘Cherubische Einzug’ in der Hagia Sophia Justinians: Aufführung und Ereignis,” in *Performativität und Ereignis*, ed. E. Fischer-Lichte et al. (Tübingen, 2003), 377–94. R. Stichel, “Τὰ σὰ ἐκ τῶν σῶν: Kaiser Justinian am Altar der Hagia Sophia,” in *Architektur und Liturgie: Akten des Kolloquiums vom 25. bis 27. Juli 2003 Greifswald*, Spätantike–Frühes Christentum–Byzanz, Kunst im ersten Jahrtausend, 21, ed. M. Altripp and C. Nauerth (Wiesbaden, 2006), 163–74. W. Schneider, “‘Abtun der Sorge und Tanz’: Der ‘Grosse Einzug’ und die Kuppel der Hagia Sophia Justinians,” in *ibid.*, 143–61. For the *Cheroubikon* in the liturgy, see n. 78 above.
92. The tenth-century *Typikon* of Hagia Sophia credits only the psalmists as performers of the hymn; Mateos, *Le Typikon de la Grand Église*, 2:6, 82, 90, 96. Codex Isidore Pyromalus states both the *psaltai* and the crowd

sang the hymn. Similarly, several later sources state that the crowd (*hō laos*) chanted the hymn: Sinai, MS gr. 973 (twelfth century) and Sinai, MS gr. 1020 (thirteenth century), *Opisanie liturgicheskikh' rukopisei*, ed. A. Dmitrievskij, 3 vols. (Kiev, 1895–1917; rpt, Hildesheim, 1965), 2:84 and 141. All these sources are assembled in E. Spyrapou, *Singers' Choirs According to the Byzantine Tradition*, Institute of Byzantine Musicology Studies, 14 (Athens, 2008), 407–9. I thank Christian Troelsgaard for this reference.

93. The *Cheroubikon*, Greek text from Taft, *The Great Entrance*, 54; and Conomos, *Byzantine Trisagia and Cheroubika*, 31–41: Οἱ τὰ χερουβῖμ μυστικῶς εἰκονίζοντες καὶ τῇ ζωοποιῷ Τριάδι τὸν τρισάγιον ὅμονον προσάρδοντες, πᾶσαν τὴν βιωτικὴν ἀποθώμεθα μέριμναν. ὡς τὸν Βασιλέα τῶν ὅλων ὑποδειξόμενοι, ταῖς ἀγγελικαῖς ἀστράτως δορυφορούμενον τάξεσιν. Άλληλοινία, ἀλληλοινία, ἀλληλοινία.

94. Future measurements of Initial Time Delay Gap (ITDG) will be very important in shedding light on this psychoacoustic effect; for ITDG, see F. Alton Everest and K. Pohlman, *Master Handbook on Acoustics* (New York, 2009), 355–62; and Beranek, *Concert Halls and Opera Houses*, 27–28, 513–19.

95. Migne, PG 87, 4001: Ἐν δὲ τῷ λέγειν τοὺς ψάλτας τὸν αὐτὸν ὅμα τοῦ λαοῦ, σημαίνεται ὅτι καὶ οἱ ἄγγελοι συνψάλλουσιν ἐν τοῖς ὑψίστοις, trans. from Troelsgaard, personal communication. This anonymous liturgical commentary of the twelfth century has connections to the Constantinopolitan practice, though it is ascribed in the manuscript to Sophronios of Jerusalem.

96. S. Havrey, *Scenting Salvation: Ancient Christianity and the Olfactory Imagination* (Berkeley, 2006); S. Brock, *Fire from Heaven: Studies in Syriac Theology and Liturgy*, Variorum Reprints (Aldershot, 2006); and Pentcheva, *The Sensual Icon*, 17–56.

97. Pentcheva, *The Sensual Icon*, 17–56.

98. M. Chion, “Wasted Words,” in *Sound Theory, Sound Practice*, ed. R. Altman (New York), 104–10.

99. M. Chion, *The Voice in Cinema*, trans. C. Gorbman (New York, 1999), 16–29.

100. Compare the absorption coefficient of sound at 250 Hz: marble, 0.01, versus cloth, 2.8; L. Egner, “Architectural Acoustics,” at http://online.physics.uiuc.edu/courses/phys193/Student_Reports/Fall03/Lisa_Egner/Architectural_Acoustics_Lisa_Egner.pdf (accessed 27 April 2010).

101. On the concept of saturated phenomenon and “excess,” see J.-L. Marion, *Being Given: Towards a Phenomenology of Givenness* (Stanford, 2002); and idem, *In Excess: Study of Saturated Phenomena*, trans. R. Horner and V. Berrand (New York, 2003).



PLATE 1 (Pentcheva, Fig. 6). *Hagia Sophia, 532–37 and 562, north aisle, sunlight glistening on the marble revetment* (© Bissara V. Pentcheva).



PLATE 2 (Pentcheva, Fig. 7). *A view of the Bosphorus in the morning on 6 December 2010* (© Bissara V. Pentcheva).

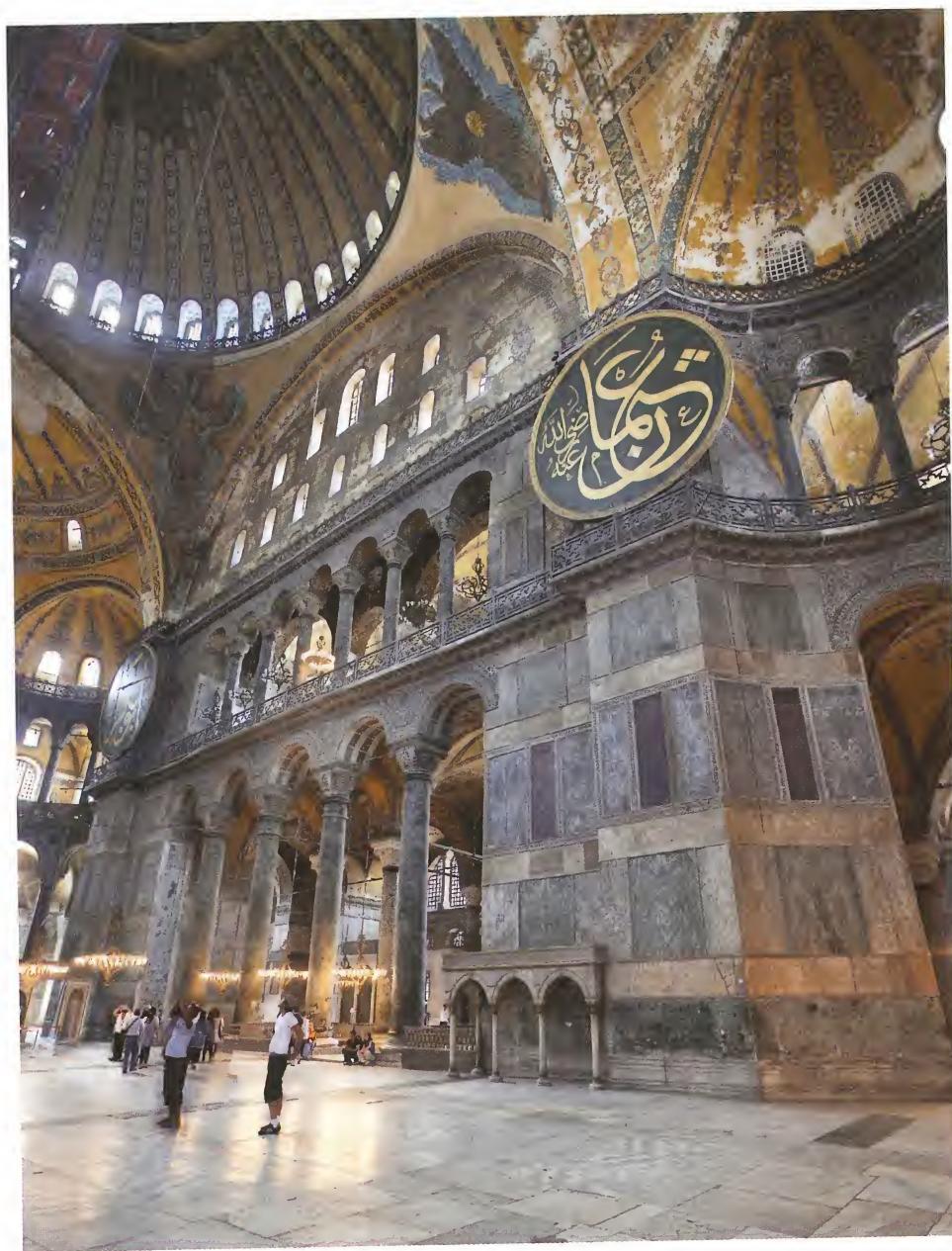


PLATE 3 (Pentcheva, Fig. 11). *Hagia Sophia, 532–37 and 562, naos and south aisle* (© Vanni / Art Resource, NY).



PLATE 4 (Pentcheva, Fig. 10). *Hagia Sophia, 532–37 and 562, Justinianic gold glass mosaic in the vaulting of the inner narthex* (© Bissara V. Pentcheva).

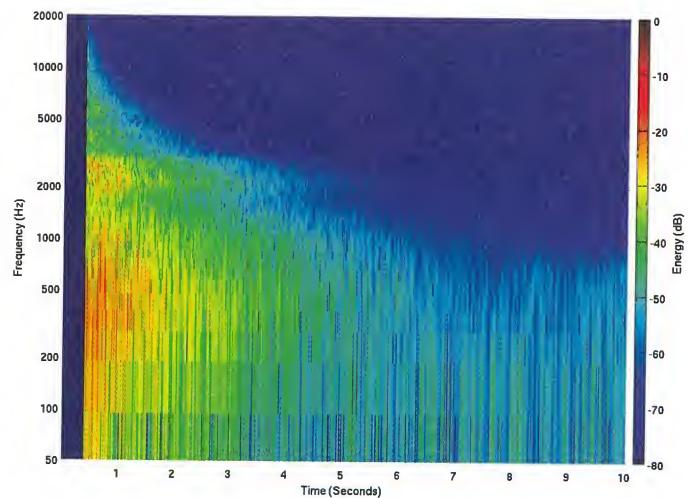


PLATE 5 (Pentcheva, Fig. 12). *Spectrogram of a balloon popping in Hagia Sophia* (© Jonathan Abel).

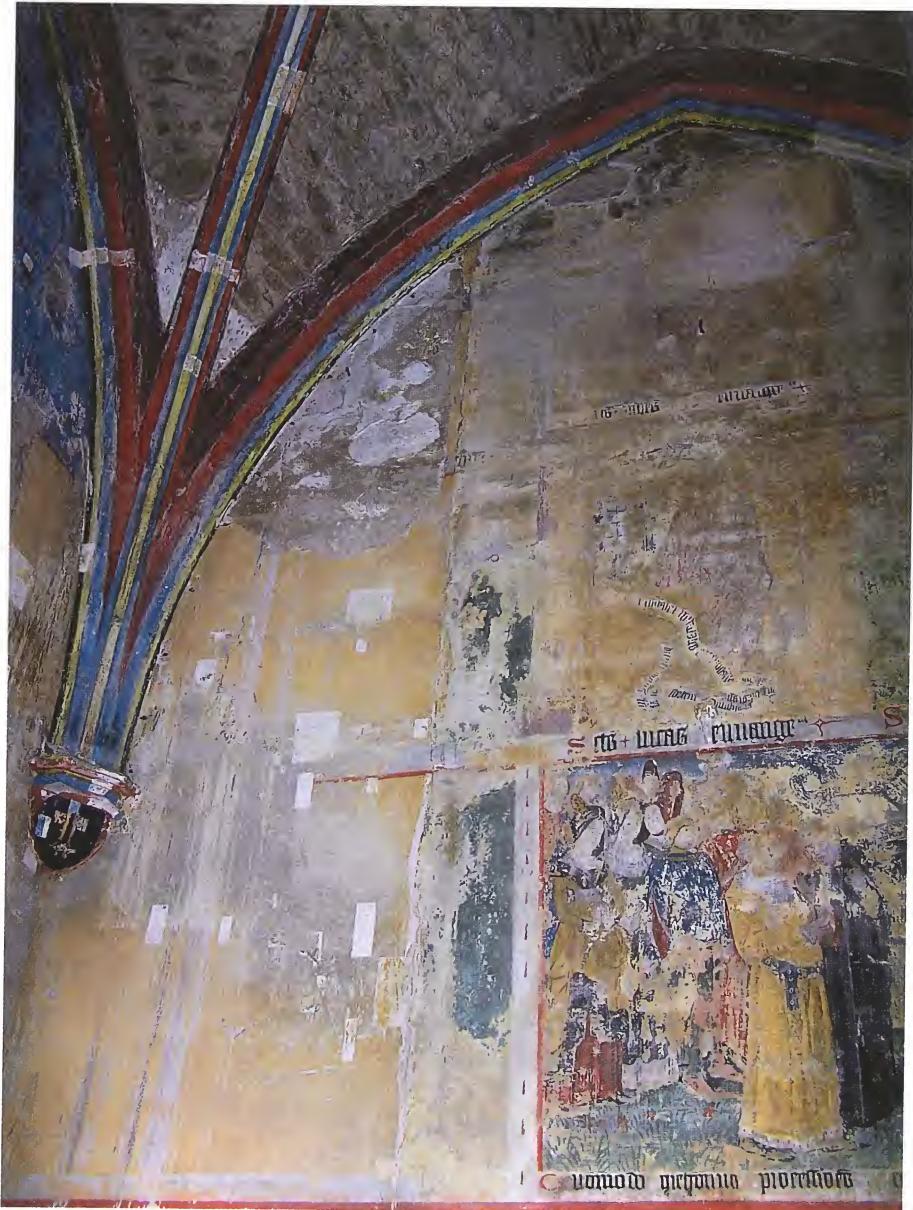


PLATE 6 (Hope, Fig. 5). *Autun, interior of the Chapelle Dorée, detail of the northwest wall* (photo: author).

